THE PENNINES AND ADJACENT AREAS - BRITISH REGIONAL GEOLOGY

DEPARTMENT OF SCIENTIFIC AND INDUSTRIAL RESEARCH
GEOLOGICAL SURVEY AND MUSEUM

BRITISH REGIONAL GEOLOGY

THE PENNINES AND ADJACENT AREAS

(*THIRD EDITION*)

by

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Based on previous editions by
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FOREWORD TO THIRD EDITION

The first and second editions of ' The Pennines and Adjacent Areas ' were written by Dr. D. A. Wray and published in 1936 and 1948 respectively. The need for a third edition so soon afterwards reflects the rapid progress in research on the rocks of the region. Consequently much of the text has been rewritten and the illustrations have been extensively altered. This work has been done mainly by Messrs. Edwards and Trotter. Mr. W. Anderson has contributed the account of the ' Yoredale Beds '.

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Plate I is reproduced by permission of Messrs. A. Horner and Sons, Settle; and Plates II, VI and VII (A and B) by courtesy of the London, Midland and Scottish Railway Company. Plate V, from a photograph by the late G. Bingley, is reproduced by permission of the Council of the Yorkshire Geological Society. For Plate IX(A) we are indebted to the late H. Wadsworth Haywood.

An EXHIBIT illustrating the Geology and Scenery of the district described in this volume is set out on the First Gallery of the Museum of Practical Geology, South Kensington, London, S.W.7.

(For description, *see* p. iv.) GIGGLESWICK SCAR

THE PENNINES AND ADJACENT AREAS

I. INTRODUCTION

THE PENNINES constitute a dominant feature in the physiography of the north of England. They extend from the vicinity of the Cheviots to the Midland Plain as a mass of high ground which is sometimes called the ' backbone of England ', a name not inappropriate to the manner in which they lie almost midway between the Irish Sea and North Sea and separate two areas of mainly low ground. Both geographically and historically this range of hills has deeply influenced the evolution of Northern England.

The region defined, for the purpose of this account, as ' Pennines and Adjacent Areas ' comprises parts of Yorkshire, Lancashire, Cheshire, Staffordshire, Derbyshire and Nottinghamshire, an area of some 8,000 square miles depicted in Fig. 1. From it is excluded that part of the Northern Pennines which comprises the Cross Fell Range, and which is described in another Handbook of this series (Northern England, 3rd edition. *British Regional Geology: Geol. Surv.*).

The Pennines and adjacent areas display a wide range of geological formations and structures, which is reflected in the variety of their scenery. So, too, economic interests cover a broad field, and there is conspicuous inequality in distribution of population, for whereas South Lancashire and West Yorkshire contain some of the most densely populated parts of Britain, the higher parts of the intervening Pennine Uplands are uninhabited.

The two coalfields which lie to east and west of the Pennines have been important factors in the industrial development of these regions; and the great coalfield of Yorkshire and the East Midlands, with its concealed extension beneath newer rocks, shows a rising output which now provides over a third of Britain's coal.

Physiography and Geology

The Pennines consist of a dissected plateau with summits ranging up to about 2,000 ft. above sea-level. Their geological structure is essentially monoclinal, and the rocks are, though with marked exceptions, tilted gently towards the east but cut off on the west by abrupt downfolding, or by faulting. Consequently many of the highest points are found along the scarped edges close to the western boundary. The strata composing the Pennine Uplands are mainly Carboniferous Limestone and Millstone Grit, with some Coal Measures. Pre-Carboniferous rocks lie chiefly to the west of the Pennines proper, between Kendal, Sedbergh and Kirkby Lonsdale; but small inliers crop out from beneath Carboniferous Limestone in the lower parts of Chapel le Dale and Ribblesdale, just north of the Craven Faults near Ingleton and Settle.

Carboniferous rocks are found on the uplands in three main areas. The Askrigg Block or Massif in the north, including the Yorkshire Fells from Stainmore Pass to the Craven district, is occupied by Carboniferous Limestone and ' Yoredale Beds '; the Central Pennines, between the Craven district and

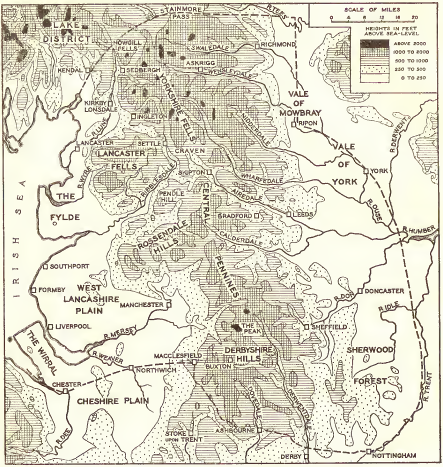

FIG. 1.—*Physical map of the Pennines and Adjacent Areas.*
The thick broken line is the boundary of the area.

the Peak, by Millstone Grit and some Coal Measures; and the Southern Pennines or Derbyshire Hills by Carboniferous Limestone of the Derbyshire Dome or Massif, flanked on west and east by Millstone Grit and Coal Measures.

On the Askrigg Block and (to a lesser extent) on the Derbyshire Dome, the uplands of limestone have become weathered to ' karst ' topography. Rock-pavements fissured by widened joints—' clints ' or ' grikes '—are interspersed with rocky gorges and cliffs or 'scars ' (Plates I, III-VI). Drainage is underground along solution-channels, and there are many large caves and, especially in the north, swallow-holes or 'pot-holes' of the most spectacular kind. In parts of both areas, but especially in Derbyshire, the working of lead and other minerals has provided further channels for the descent of water, and has added its contribution to the scenery in the form of open clefts and long lines of spoil-heaps. A characteristic flora lives on these limestone hills, and where soil is thick enough the sweet pasture supports sheep and cattle.

The ' Yoredale Beds ', a rhythmic series of shales, limestones and sandstones, are confined to the Askrigg Block, and form a broad-featured country of ' step-topography ' and waterfalls, as at Hardraw Scar. They are well exposed in the flanks of certain isolated hills—Ingleborough, Whernside, Penyghent, Shunner Fell, Lovely Seat and others—which rise above the generally uniform level of the plateau surface of the Block as ' monadnocks ' above an ancient peneplain.

Between the northern and southern areas of limestone, and stretching from Skipton to the Peak, lie the Central Pennines, a narrow belt of ' gritstone ' country. Here the shales and sandstones of the Millstone Grit Series form high hills occupied by moors and peat-mosses, with crags and ' edges ' of grey sandstone, and stony 'cloughs' descending to deep landslip-cumbered valleys—some in their original beauty, some ponded at intervals behind reservoir-dams, and some crammed with settlements of the textile industry, which was early attracted by the water-supply; for the soft water which pours off the sodden ' tops ' is almost the only material asset of these regions. The higher ground is uncultivable and barely pasturable and is, with rare exceptions, uninhabited. Nor are the wet, sour soils on the lower slopes of great agricultural value. Albeit these lonely uplands, though often harsh in their angularity, possess a strange, austere dignity and even, in places, grandeur: and lying between thickly populated regions they have great recreational value[1].

The Howgill Fells are mountainous tracts of Lower Palaeozoic rocks separated from the Pennines by the Dent Fault-line. Like the neighbouring country between Kendal and Kirkby Lonsdale they belong, topographically and geologically, to the Lake District, which marches with them on the west.

Further south on the western side of the Pennines lies an area of broad folds of south-westerly trend which, as a group, have given rise to high-lying land that is divided into two main areas by the River Ribble. These fells, together with the Pennines, face the prevailing south-westerly winds to cause the high rainfall and consequent high humidity that, in the first instance, attracted the cotton industry to Lancashire. The broad elevated tract to the north of Lancaster is known as the Lancaster Fells. It is a bleak moorland presenting the peat-moss and gritstone type of topography of the Central Pennines. By contrast the broad vale of Ribblesdale presents a subdued shale-and-limestone topography that is, however, diversified by picturesque reef-knolls. On the southern side of the Ribble the relatively high-lying Burnley Syncline presents typical coalfield ground that gives place gradually to the gritstone topography of the Rossendale Hills.

A coastal plain of rich agricultural land flanks these areas on the west and south, widening in the latter direction into the broad plain of Cheshire. In the north there is the Fylde, which, in addition to agriculture, supports a chemical industry based on the abstraction of rock-salt from the Preesall Saltfield.

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[1] Access to these areas has recently been improved by legislation and by gifts to the National Trust. Much of the Peak District National Park, especially its northern part, consists of ' gritstone ' country.

The plain of south-west Lancashire, bounded on the north by the River Ribble and on the south by the River Mersey, sweeps inland to the Pennines to include the main part of the Lancashire Coalfield. At one time lying around Wigan, the economic centre of this coalfield is shifting southwards as the coal is worked deeper beneath the Permo-Triassic rocks, with the area between St. Helens and Manchester potentially the most important.

The Cheshire Plain extends beyond the southern margin of our district. It is occupied by Permo-Triassic rocks that are thickly covered by Glacial Deposits. The latter give rise to the rich agricultural land for which Cheshire is renowned. The highest division of the Permo-Trias contains thick beds of rock-salt, and Cheshire produces over 82 per cent of the salt extracted (as brine) in Britain. The brine is converted into soda-ash to form the basis of the chemical alkali industry of Merseyside, and into white salt.

The Yorkshire and East Midlands Coalfield (East Pennine or Don-Trent Coalfield of some authors) extends from Leeds and Bradford 60 miles southwards to Nottingham, and eastwards beneath the Permo-Trias for an unknown distance beyond the confines of the region here being described. Its proved extent is about 3,000 square miles. Its resources of coal have led to intense industrial development in the West Riding of Yorkshire and adjacent parts of Derbyshire—development which somewhat obscures an agricultural region of former repute. Smelting of clay-ironstones from the Coal Measures dates back to the Roman Period, and in medieval times grew, under monastic protection, into an industry of some importance. In the nineteenth century it became concentrated into large ironworks such as those at Low Moor, Staveley and Stanton: also the steel centre of Sheffield, which, however, used some Swedish iron from early times. At the present day all the ores of iron are brought from areas outside the coalfield.

In Yorkshire and East Derbyshire production of coal increased rapidly throughout the period of the industrial expansion of England; but at the present day the richest areas in the west of the coalfield are becoming exhausted, and development is most active among the deeply-buried measures of the 'Concealed Coalfield' in Nottinghamshire and Yorkshire, where great reserves of coal have been proved.

In the east the Carboniferous rocks of Yorkshire and the East Midlands are overlain unconformably by the several divisions of the Permo-Trias, each cropping out in a belt roughly parallel to the Pennines and each giving its distinctive landscape. The Magnesian Limestone extends in a narrow strip from the Tees to the Trent with a low but marked escarpment facing west—a feature duplicated where marls divide the limestone into two. It gives attractive cliff-scenery where its outcrop is breached by rivers, and its surface constitutes good farm-land. It provides building stone and refractory dolomite. The outcrops of the higher beds of the Permo-Trias are largely obscured by Glacial and Recent deposits to the north of Doncaster; but to the south the light, somewhat infertile soils of the Bunter Sandstone support the woodlands of Sherwood Forest. This forest once extended eastwards onto the strong red land of the Keuper Marl, now almost entirely farmed. The agricultural character of the region occupied by the Permo-Triassic rocks and their overlying Drifts is being modified in the west by the spread of coal-mining; towns and villages are being extended, and new settlements are growing up around the collieries. Extraction of coal is spreading beneath the low-lying land west of the Humber—flat regions of Glacial and Recent sands, silts and clays with some marine ' warp '. These regions, barely above sea-level and containing much original fenland, are for the most part artificially drained and very fertile.

FIG 2.—*Geological map of the Pennines and Adjacent Areas.*

Geological Sequence

The oldest rocks which crop out within the Pennines are the Ingletonian slates and grits, but other probable Pre-Cambrian beds have been found in borings. Cambrian is suspected beneath the Eakring oilfield in Nottinghamshire, and Ordovician and Silurian crop out in the north-west; Devonian is doubtfully present, but Carboniferous rocks are widespread, and probably attain their thickest development in Britain. Permo-Triassic rocks lie along both flanks of the Pennines, but higher Mesozoic and Tertiary formations are absent. The Pleistocene is widely represented by a varied series of clays, sands and gravels which are direct or indirect products of glacial invasion and which include periglacial beds of great interest. Recent deposits include parts of the wide sheets of sand, silt and clay along the lower courses of the rivers pouring into the Humber; the stretches of hill-peat on the uplands of the Pennines; and the extensive sand-dunes and associated peat-beds which fringe the low-lying coasts of Lancashire and Cheshire. The geological formations represented are summarized in the following table:—

QUATERNARY

RECENT AND PLEISTOCENE

Alluvium, Peat, Blown Sand, water-deposited clay, silt and sand, Cave-Deposits, River-gravels, Head (solifluxion-drift), Boulder Clay, Moraine, associated Sand and Gravel.

(*Tertiary rocks missing*)

MESOZOIC

(*Cretaceous and Jurassic Rocks missing*)

PERMO-TRIASSIC OR NEW RED SANDSTONE

Keuper Marl.

Keuper Sandstone and Waterstones.

Bunter Sandstone (the lower beds passing laterally into Permian).

UPPER PALAEOZOIC

PERMIAN Limestones, marls, breccias and sandstones.

CARBONIFEROUS

Coal Measures: mudstones, sandstones and coals.

Millstone Grit Series: mudstones, sandstones and thin coals: with upper part of 'Yoredale Beds' (mudstones, limestones and sandstones).

Carboniferous Limestone Series: mudstones, limestones, rare sandstones: with lower part of 'Yoredale Beds': conglomerates of Eakring.

DEVONIAN (?)

'Upper Devonian' mudstones and limestones of Skipton: ? lower part of conglomerates of Eakring: ? conglomerates of Rawthey valley.

LOWER PALAEOZOIC

SILURIAN

Ludlow Series: mudstones, flags, grits.

Wenlock Series: flags, grits.

Llandovery or Valentian Series: shales with thin limestones.

ORDOVICIAN

Ashgill Series: shales and limestones.

CAMBRIAN (?)

Mudstones and quartzites at Eakring.

PRE-CAMBRIAN (inferred)

Ingletonian Series: slates, grits, conglomerates: rocks of Uriconian type in Woodale Boredale near Buxton: ? part of quartzites at Eakring.

HISTORY OF RESEARCH

The Pennines form such a dominating physical feature in the northern half of England that they have attracted the attention of geologists from the earliest periods in the study of the science. It was a Yorkshire physician, Martin Lister, who (in a communication to the Royal Society in 1684) first appears to have envisaged what we now know as a geological map, which should, according to him, 'show the distribution of the various sands and clays such as are chiefly found in the north parts of England'. In the Pennines, also, it was first recognized in the following century by a Yorkshire priest, John Michell, that there was an orderly sequence of the exposed edges and surfaces of successively newer rocks dipping away on either side from a main central axis. Michell, to whom Sedgwick later assigned 'a foremost place among the founders of modern geology ', appears to have been well acquainted with the general sequence of the strata from the Coal Measures to the Chalk.

The pregnant observations made by these pioneers, however, seem to have led to no serious study of the geology of the region before the investigations of William Smith, ' Father of English Geology ', at the beginning of the nineteenth century. Smith resided for a long period in Yorkshire and, apart from the pre-Carboniferous rocks, became fairly well acquainted with the geological succession: he prepared the first geological maps of the region. From his time onwards an ever-increasing band of workers has been attracted to the area, while the literature dealing with it has today reached formidable proportions. It will, therefore, be possible in this chapter to refer only in a general way to outstanding contributions that have been made to the geology of this region.

Foremost among the pioneer workers was John Phillips, nephew of William Smith, who was originally brought to Yorkshire by his uncle. Phillips devoted himself assiduously to the study of the Pennines, and his researches on the geological structure and the succession, together with his unrivalled descriptions of the fossil contents, were first published in 1836. This account is still one of the standard works on the area, and indeed was so complete that no further advance of note in the study of the Pennine Uplands took place until the six-inch to the mile survey of the area was carried out by the Geological Survey some thirty years later.

That eminent geologist, Adam Sedgwick, was born at Dent in 1785. The older rocks of his native district early attracted his attention, and his account of the Permian rocks published in 1829 is the basis of the present classification.

In 1817 John Farey, a land surveyor and pupil of William Smith, published *A General View of the Agriculture and Minerals of Derbyshire*, which is the first clear account of the succession of Carboniferous and other strata in that county and is one of the classics of English Geology. Valuable observations were also being made about this time by Whitehurst, and in 1793 W. Martin described and figured fossils from the Carboniferous Limestone, the enlarged work being re-issued in 1809 as a monograph entitled *Petrificata Derbiensia.*

The researches of these pioneers coincided with extensive developments in the Pennine coalfields which led to a wide interest being taken in the geology of these districts. In 1832, a geological map of the Lancashire Coalfield was published by Elias Hall, a native of Castleton in Derbyshire and a fellow-worker of John Farey. This was followed by a general account of the geology, and a list of the organic remains found in the various beds, compiled by his friend, Francis Looney. At this period numerous provincial geological societies were formed, mainly with the object of facilitating study of the geology of the coalfields; and prominent among the earlier members of these were Binney in Lancashire and Sorby in Yorkshire.

The Geological Survey was established in 1835, but it was not until fifteen years later that mapping was commenced in Derbyshire at the southern end of the Pennines. This was later extended into the adjacent parts of Nottinghamshire, Yorkshire, Cheshire and Lancashire. Among the earlier surveyors were John Phillips, Aveline, Le Neve Foster, Hull, Dakyns, Clifton Ward and A. H. Green. The first maps were issued hand-coloured on a scale of one-inch to the mile; but within a few years six-inch to the mile Ordnance Survey maps were available, and subsequent geological work was executed on this scale. Memoirs descriptive of the areas surveyed were issued at intervals, the most comprehensive being that on the Yorkshire Coalfield, published in 1878 under the editorship of A. H. Green and R. Russell. It was not, however, until the end of the nineteenth century that the area had been completely surveyed on the six-inch scale, the latest maps to be produced being those of the Northern Pennines.

The one-inch and published six-inch maps of the Geological Survey are now usually issued in both ' Solid ' and ' Drift ' editions when a considerable amount of Glacial drift is present on the ground, but on the earlier maps no Glacial deposits were shown. The first maps to show the distribution of Glacial drifts were published in 1871, and since then both drift and solid editions have been available for most areas. With the rapid progress of mining and the consequent accumulation of much new information, revision of the older maps of the Pennine coalfields became necessary. Thus between the years 1903 and 1909 the Nottinghamshire and Derbyshire Coalfield was re-surveyed by the officers of the Geological Survey. Revision of the Lancashire Coalfield was commenced in 1921 and of the Yorkshire and East Midlands Coalfield in 1923. These revisions are now completed. The published results of this work are given on pp. 84, 85.

Although the majority of the memoirs issued by the Geological Survey are descriptions of the areas surveyed, there are several volumes which deal with special subjects with particular reference to the Pennines and adjacent areas. Among these is that on the Concealed Coalfield of Yorkshire and Nottinghamshire, first published in 1913, of which a second edition appeared in 1926 and a third in 1951. There are also several volumes issued between 1915 and 1930 dealing with mineral resources, and memoirs have been published on the water supply of East Yorkshire, Nottinghamshire and Derbyshire.

The researches of independent geologists have been considerable, and it is possible to indicate but a small proportion of them. Sedgwick was the first of a long line of Cambridge men to investigate the pre-Carboniferous, and notable among recent work on the older rocks is that of Rastall on the Ingletonian Series and of King and Wilcockson on the Lower Palaeozoic.

Since the original work of Phillips and Farey, the Carboniferous Limestone has received the attention of many geologists. Garwood established a classification in the north-west of England, similar to that founded by Vaughan in the south-west, based primarily on corals and brachiopods: and his inspiration led a band of enthusiasts including Hudson and Parkinson (see references on pp. 85, 86) to tackle the problems presented by changes in faunal and lithological facies and other peculiarities of this formation. Among work on the igneous rocks of the Carboniferous that of Bemrose is best known.

The source and origin of the materials of which the Millstone Grit is composed were the subject of petrological investigations by Sorby in 1859 and Gilligan in 1920. The marine fauna in the shales of this formation has been studied by Hind; and W. S. Bisat, in an outstanding contribution in 1924, established the zonal classification of the Millstone Grit and much of the Lower Carboniferous, based on the goniatites. Others have extended this work both in the Pennine uplands and farther afield in Britain and on the Continent.

Literature on the Coal Measures has become voluminous. Notable researches have been made by Binney, Gibson, Kendall, Fearnsides and others on stratigraphy and structure; by Hind, Trueman, Wright and Eagar on the non-marine lamellibranchs; by Williamson and Kidston on the flora; and by

Stopes, Hickling and Raistrick, and latterly by officers of the Coal Survey Laboratories, on the physical and chemical constitution of coal. In respect of the detailed stratigraphy, marine and non-marine palaeontology, and structure of the Coal Measures, the contributions of officers of the Geological Survey, owing to their preoccupation with the economics of this formation, are now of paramount importance; and the classic researches of Green, Russell, Hull and others have been extended and elaborated of recent years by the production of revised maps and memoirs covering most of the ground occupied by the Pennine coalfields (see pp. 84, 85).

Since 1939 the search for oil beneath the East Pennine Coalfield, and its production in East Nottinghamshire, has entailed the drilling of over 100 miles of well, at depths varying down to 7,476 ft. The interpretation of the well-logs, in which Lees and Taitt have taken a leading part, has profoundly increased our knowledge of the succession and structure of the rocks in this district.

The Permo-Triassic or New Red Sandstone formation has been studied by Sedgwick, Hull and others; and more especially in recent times by Sherlock, who demonstrated in Nottinghamshire the lateral passage of Permian limestones and marls into Triassic sands. He showed, incidentally, that some parts of the Upper Palaeozoic and Mesozoic rocks of the traditional classification (see table on p. 6) were deposited simultaneously.

Pleistocene and Recent deposits of the Pennine region have been the subjects of study, and of controversy, since the early days of geological science. Among contributions of the first workers those of Tiddeman and Goodchild are outstanding. Kendall provided an admirable summary of the views current in his time (and including in large part the results of his own work) in his 1924 collaboration with H. E. Wroot. And the flood of publication on these subjects continues to the present day. The cave-deposits of Derbyshire and north-west Yorkshire, standing for the most part outside the arena of disputation, have been described by Mello, Boyd-Dawkins, Jackson and Armstrong.

The writers wish to acknowledge the ready assistance they have received from their colleagues on the Geological Survey. In the choice of typical fossils to illustrate the exhibit and also in checking the palaeontology, Dr. C. J. Stubblefield has taken the chief part. He and Dr. R. Crookall are responsible for the illustrations of fossils in the present handbook.

II. PRE-CARBONIFEROUS ROCKS

PRE-CAMBRIAN

INGLETONIAN rocks occur in two small inliers at Chapel le Dale and Horton in Ribblesdale, close to Ingleton in North-West Yorkshire (Fig. 4). They consist of slates with bands of grit, and coarse arkose or conglomerate which is quarried as 'Ingleton Granite'. No determinable fossils have been found in them, and in many respects they resemble the Longmyndian rocks of Shropshire. Observed junctions with Lower Palaeozoic rocks appear to be either faulted or unconformable.

In a borehole at Woodale, 2 miles E.S.E. of Buxton, altered volcanic rocks of Uriconian type were found beneath Carboniferous Limestone, from 900 to 1,024 ft. from surface. In the Nottinghamshire oilfields the deepest well, Eakring No. 146, finished at 7,476 ft. in quartzites which are possibly pre-Cambrian in age (but see below). Three other test-borings for oil, farther east and outside the limits of the present area, finished in somewhat similar rocks which were thought likely to be pre-Cambrian.

These ancient rocks, compacted, folded, sheared and denuded, form a basement to the whole region, on or against which the later Palaeozoic sediments were deposited.

LOWER PALAEOZOIC ROCKS

Ordovician and Silurian strata crop out in the Howgill Fells and the uplands southwards to Kirkby Lonsdale (Fig. 3), and in small inliers on the northern side of the North Craven Fault near Ingleton (Fig. 4). Evidence suggesting the presence of other pre-Carboniferous rocks is afforded by the boreholes mentioned below.

CAMBRIAN

In well No. 146 at Eakring (see above) the rocks from 7,200 to 7,476 ft. are dark grey phyllitic mudstones and quartzites, among which traces of fossils were detected. They are therefore likely to be, at least in part, of Lower Palaeozoic and possibly Cambrian age: although Cambrian rocks have been proved beneath the Permo-Trias at Leicester, 35 miles south of Eakring, they appear to be absent from most of the Pennine region.

ORDOVICIAN

Small inliers of Ordovician rocks occur along the eastern slopes of the Howgill Fells, the best sections being in the vicinity of Cautley.

In the Ingleton district rocks of this age occur in places along the northern side of the North Craven Fault. Here the Lower Palaeozoic rocks, comprising both Ordovician and Silurian, are folded in a broad synclinorium trending east and west with an easterly pitch, the Ordovician strata outcropping in the cores of the subsidiary flanking anticlines. The larger areas are in the neighbourhood of Wharfe and Norber, and near the head of Crummackdale. Two small inliers also occur at the foot of Chapel le Dale to the north of Ingleton.

(For description, *see* p.iv.) THORNTON FORCE INGLETON

(For description, *see* p. iv.) (A 7577)

A.—UNCONFORMITY, ARCOW WOOD, HORTON-IN-RIBBLESDALE

(For description, *see* p. iv.) (A 7571)

B.—GORDALE SCAR

Owing to the isolated and scattered nature of the exposures considerable difficulty has attended the correlation of the Ordovician rocks of the Central and Southern Pennines with those of other areas. It now seems that only the highest, Ashgill, division of the Ordovician is represented, with the following subdivisions: Upper, with *Dalmanitina mucronata* fauna and including the

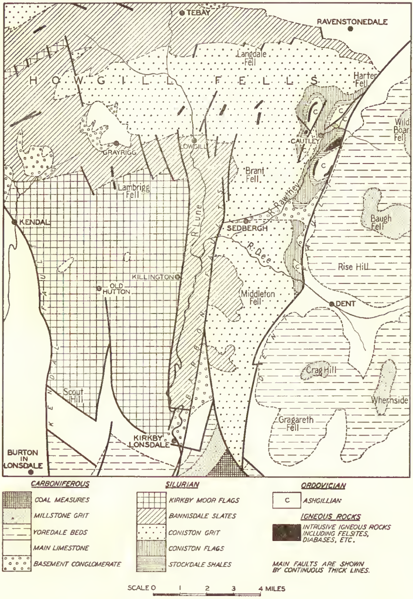


FIG. 3.—*Geological sketch-map of the Fell country between Tebay, Kendal and Kirkby Lonsdale.*

Ashgill Shales; Middle, with *Phillipsinella parabola* fauna and including the *Staurocephalus* beds and *Dalmanitina robertsi* beds; Lower, with *Diacalymene marginata* fauna—the *Calymene* Beds.

Ashgill Series.—In the Cautley district the Lower Ashgill (Coniston Limestone Series) consists of dark shales with bands of impure limestone in which the trilobite *Diacalymene* is the most characteristic fossil. These beds are represented in the Ingleton and Horton-in-Ribblesdale inliers by fossiliferous limestone and mudstone yielding trilobites such as *Diacalymene*, *Chasmops* and *Cybele*, together with numerous brachiopods.

Near Cautley the Middle and Upper subdivisions of the Ashgill consist of shales with graptolites such as *Dicellograptus*, *Diplograptus* and *Climacograptus*, as well as the characteristic trilobites *Phillipsinella* and *Dalmanitina*. At Horton in Ribblesdale and Ingleton they consist of calcareous shales with the trilobites *Trinucleus* and *Staurocephalus*, and among the graptolites *Dicellograptus* and *Diplograptus* are the commonest genera. A prominent band of conglomerate ranging up to 10 ft. in thickness occurrs in the upper part of the succession in the Horton-in-Ribblesdale district.

Igneous rocks, including felsites and volcanic ashes, are associated with the Ordovician rocks in both the Howgill Fells and the Ingleton district. They are most extensively developed in the higher Ashgill beds.

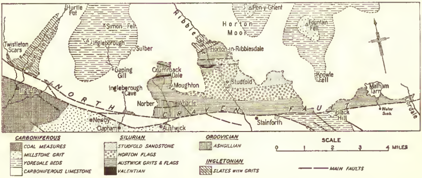


FIG. 4.—*Map showing distribution of Lower Palaeozoic rocks in the Ingleborough district.*

SILURIAN

The Silurian formation covers considerable areas in both the Howgill Fells and the Horton-in-Ribblesdale district. With the exception of the small patches of Ordovician strata in the vicinity of Cautley, the Howgill and adjacent fells as far south as Kirkby Lonsdale consist almost entirely of Silurian grits, shales and flagstones. The large inlier of Lower Palaeozoic rocks along the northern side of the Craven Faults at Horton in Ribblesdale also consists in the main of Silurian grits and sandstones.

The Silurian rocks are on the whole coarser grained and of a more arenaceous character than the underlying Ordovician. Graptolites occur at many horizons, but whereas the Ordovician is characterized by graptolites of somewhat complex character such as *Pleurograptus*, *Leptograptus* and large *Diplograptus*, the Silurian strata are distinguished by other forms like *Monograptus* and *Cyrtograptus*.

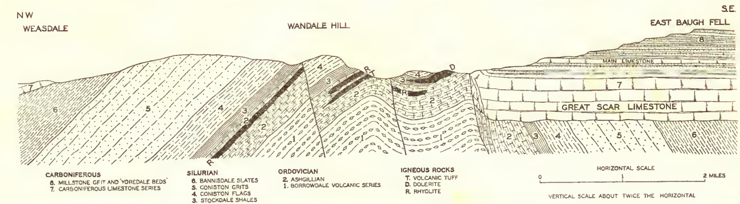


FIG. 5.—*Section showing the geological structure of the Howgill Fells.*

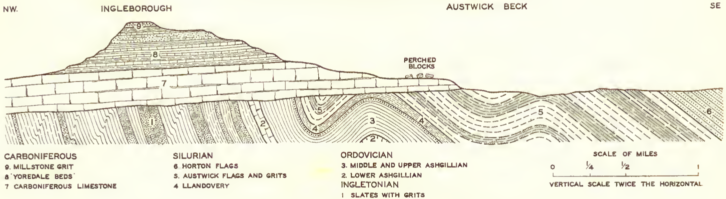


FIG. 6.—*Section across the Ingleborough district.*

Igneous rocks are unimportant in the Silurian as compared with the Ordovician. In the Howgill Fells, however, the rocks of this age are invaded in many places by small dykes consisting mainly of lamprophyres rich in mica.

Three of the main divisions of the Silurian are represented in both the Howgill Fells and the Horton-in-Ribblesdale district. These are, in ascending order, the Llandovery or Valentian Series, the Wenlock Series and the Ludlow Series.

Llandovery or Valentian Series.—This series is represented by the Stockdale Shales, which in the neighbourhood of Cautley consist of dark shales with thin limestones. The principal fossils are graptolites, including species of *Monograptus*, and occasionally trilobites belonging to the genus *Phacops*. Near Horton in Ribblesdale and in Crummackdale to the east of Ingleton the Valentian is represented by dark shales with graptolites, among which the commonest forms are species of *Monograptus*, *Climacograptus* and *Dimorphograptus*. With these occur thin bands of calcareous mudstone almost wholly made up of trilobite fragments, *Phacops elegans* being the most characteristic species.

Wenlock Series.—In the Howgill Fells the Wenlock beds form a narrow belt along the western side of the Dent Fault, extending almost as far south as Middleton Fell. They consist of the massively jointed Coniston Flags, and in places are strongly cleaved. Graptolites, chiefly species of *Monograptus*, occur at many horizons. The corresponding beds in the Horton-in-Ribblesdale district are the Austwick Flags and Grits which also yield abundant graptolites, principally species of *Monograptus* and *Cyrtograptus*.

Ludlow Series.—The Ludlow beds of the Howgill area consist largely of banded micaceous sandy strata alternating with grit bands. In a general way the grits serve to distinguish the Ludlow rocks from the more argillaceous flags of the underlying Wenlock Series. The Ludlow Series attains a considerable thickness and is divided into the following groups:—

4. Kirkby Moor Flags.	2. Coniston Grits.
3. Bannisdale Slates.	1. Coldwell Beds.

The Coldwell Beds* are mainly graptolite-bearing mudstones. The Coniston Grits on the other hand consist of massive grey gritstones, and occupy the greater part of the high ground in the Howgill Fells. They pass up conformably into the Bannisdale Slates. The highest beds, the Kirkby Moor Flags, are mainly flagstones and contain a well-marked starfish bed with *Urasterella* and *Palaeasterina*. They form a broad spread in the country between Kendal and Kirkby Lonsdale.

In the Horton-in-Ribblesdale district the Ludlow rocks are represented by the Horton Flags and the Studfold Sandstone. These are confined to the centre of the main syncline, the axis of which trends in an east and west direction through Studfold village. The Horton Flags, which can be correlated with the Coldwell Beds of the Howgill Fells, consist of a uniform series of flagstones with graptolites, *Monograptus* being the commonest generic form. To this group belong the Moughton Whetstones, fine-grained compact silt-stones with concentric or box-like dull red and green bands (these may be seen at the head of Crummackdale). The Studfold Sandstone succeeds the Horton Flags

* These beds, which underlie the Coniston Grits in the Cautley district, are not separately distinguished on the Geological Survey maps.

and in lithology strongly resembles the Austwick Flags and Grits. It appears to be the local representative of the Coniston Grits of the country to the west.

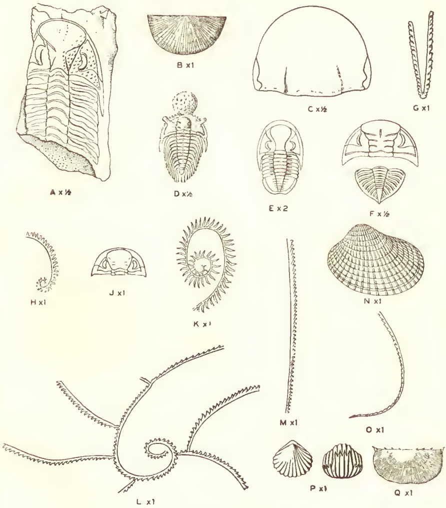


FIG. 7.—*Some characteristic Ordovician and Silurian fossils.*

Ashgillian: A, *Chasmops marri* Reed; **B,** *Sowerbyella sericea* (J. de C. Sowerby)[1]; **C,** *Illaenus bowmanni* Salter[1]; **D,** *Staurocephalus murchisoni* Barrande[1]; **E,** *Phillipsinella parabola* (Barrande); **F,** *Dalmanitina mucronata* (Brongniart); **G,** *Dicellograptus anceps* (Nicholson). **Llandovery Series: H,** *Monograptus triangulatus* (Harkness); **J,** *Phacops elegans* (Sars and Boeck); **K,** *Monograptus convolutus* Hisinger. **Wenlock Series: L,** *Cyrtograptus murchisoni* Carruthers; **M,** *Monograptus riccartonensis* Lapworth. **Ludlow Series: N,** *Cardiola interrupta* J. de C. Sowerby; **O,** *Monograptus nilssoni* (Barrande); **P,** *Camarotoechia nucula* (J. de C. Sowerby), two views; **Q,** *Chonetes striatellus* (Dalman).

[1] These drawings represent species of which related forms are found in the region.

DEVONIAN (?)

The mudstones and limestones in the Skipton Borehole, if correctly assigned by Hudson to the *Cleistopora* Zone of the Avonian (p. 24), would be regarded by some geologists as belonging to the upper part of the Devonian.

Rocks which possibly represent the non-marine (Old Red Sandstone) facies of the Devonian (though in no case have they yielded fossils) are the red conglomerates which crop out in small patches close to the Dent fault-line in the valley of the Rawthey east of Sedbergh: but they may equally well be the basement-conglomerates of the Carboniferous (p. 24). Also the lower part of the reddish conglomerates in Well No. 146 at Eakring (p. 30) which, again, are perhaps of Carboniferous age like the conglomerates above them.

III. THE CARBONIFEROUS SYSTEM:

INTRODUCTION

ABOUT FOUR-FIFTHS of the area described in this book is occupied by Carboniferous rocks at outcrop, and most of the remaining fifth is underlain by them at depth. They are of immense economic importance and include two of the greatest British coalfields. The major divisions ot these rocks, with their generalized thicknesses and approximate European equivalents, are shown in the table below.

DIVISIONS OF THE CARBONIFEROUS SYSTEM

	Approx. max thickness in ft.
Upper Carboniferous	
Coal Measures (Westphalian)	5,000
Millstone Grit Series (Namurian)	6,000
Lower Carboniferous	
Carboniferous Limestone Series (Dinantian, subdivided into Viséan or Upper Avonian and Tournaisian or Lower Avonian)	5,000

This classification is based in the first instance on lithology. The Carboniferous Limestone Series contains massive limestone as its most noticeable rock-type; the Millstone Grit Series is essentially a mudstone-sandstone formation; and the Coal Measures are the same, but with less sandstone and many beds of coal.

These major divisions represent successive phases of deposition in an area which was subsiding irregularly, and in which sedimentation kept a rough pace with subsidence. In most parts of the Pennine region the initial phase was one of dominantly clear water in which limestone was formed. Uplift of neighbouring land, or increased rainfall on that land, led, earlier in the Yoredale country of the north than in the south, to recurrent invasions of deltaic sediment, and thus a rhythmic succession of mudstones and sandstones is characteristic of the higher beds of the Millstone Grit Series. Firmer establishment of deltaic conditions led to deposition of the Coal Measures, in which most sedimentary cycles ended with the silting-up of large areas; on these grew subaerial vegetation which, where favoured by reducing or non-oxidizing conditions, accumulated until it was overtaken by renewed sedimentation and turned into coal. There is no sharp dividing-line between these formations: mudstones and sandstones, and even occasional coals, occur in the Carboniferous Limestone Series; limestones persist into the rhythmic units of the Millstone Grit, and the marine phases characteristic of those units are found occasionally in all but the highest beds of the Coal Measures.

This is an excessively simplified description of a most complex group of beds, laid down under unstable conditions which induced spectacular lateral change in both lithology and fauna, and even strong local unconformity, and which were rounded off by the climax of one of the major orogenies of geological history.

Variations in Lithology and Fauna

When the Carboniferous Limestone is closely examined it is found to vary considerably in character in its different parts. Different lithological types, each characterized by a distinctive fauna, can be recognized; and it becomes important to appreciate these variations when studying the stratigraphy of this series. More particularly is it necessary to distinguish zonal faunas from faunas of lithological phases, and in this respect a major problem still awaiting solution is the relation between coral-brachiopod faunas of the ' massif' and goniatite-lamellibranch faunas of the ' basin '.

Massif and basin facies.—The dominant variations in Lower Carboniferous sediments are related to their deposition in two distinct environments. The massifs, or ' rigid blocks ', appear to have been relatively stable regions of delayed subsidence (they were not generally submerged until fairly late in the Lower Carboniferous period); the basins appear to have subsided more freely and thus received substantially greater quantities of sediment. Further, Carboniferous rocks on the massifs are little folded, those in the basins are sometimes much folded.

In the clear water over the massifs were laid down the well-bedded ' standard limestones ' with a fauna of corals, brachiopods, crinoids and algae, and with them the very shallow-water beds of the ' lagoon-phase ' with porcellanous limestones and dolomites, oolites, and (in parts of Britain) radiolarian cherts. Into the open seas between and around the massifs was poured the sediment which provided the deposits of ' basin-facies '. These comprise dark, argillaceous, often cherty limestones of ' modified limestone ' and ' *Zaphrentis* ' phases, with a meagre fauna of simple corals such as *Zaphrentis* and *Cyathaxonia*, and dark shales with thin limestones of the so-called ' Culm-phase ' (they differ considerably from the Culm of South-West England and have been called ' Bowland Phase '), in which goniatites and thin-shelled lamellibranchs dominate the fauna.

Within the present area the known massifs are those of Askrigg and Derbyshire, and a further one in the south-east, of unknown extent but embracing the oilfield-district of Nottinghamshire (p. 30). Basin-deposits occur extensively in Ribblesdale, and are found on the north and west sides of the Derbyshire massif; also in the Nottingham area where they have been proved in oil-borings just south of the region here considered.

The massifs were bounded in places by fault-lines along which movement took place during deposition, e.g. the Craven Fault-belt and the Castleton district of North Derbyshire: but in some areas the boundaries between massif and basin appear to have fluctuated widely as the Dinantian sea crept up the flanks of the massifs. Along these marginal belts are apt to be concentrated—though they occur elsewhere—the reef-limestones described below.

Reef-limestones.—The bedded limestones of massif facies, and occasionally those of basin facies, contain sporadic masses of unbedded or obscurely bedded, compact, crystalline or shelly rock, of lenticular shape and wide range of size, over which succeeding strata are draped with quaquaversal dips. These, the ' knoll-reefs ' or ' reef-knolls ' of Tiddeman, are undoubted reef-limestones in the sense that they accumulated on the floors of shallow seas, partly by growth of shells, algae and other organisms under exceptionally favourable conditions, partly perhaps by direct precipitation comparable with the formation of tufa.

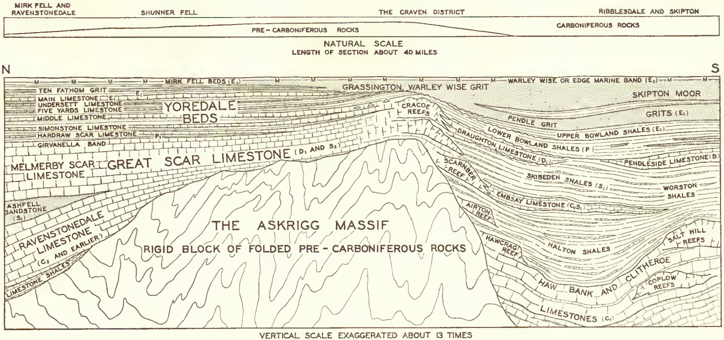


FIG. 8.—*Diagrammatic cross-section showing the succession and relations of the Lower Carboniferous and Millstone Grit rocks in Yorkshire.*

(Based on R. G. S. Hudson)

Other, less characteristic, masses of reef-limestone have been stated to exist. Bond, for example, claims to recognize the following types: *apron-reefs*, which are submarine screes banked at about 30° against steep faces of either reefs or cliffs; *flat reefs*, forming extensive spreads on the margins of massifs, and recognizable mainly by their fauna; and *unbedded reefs*, consisting of massive limestone and found on the scarped southern edge of the Askrigg Massif, where they appear to pass laterally northwards into standard limestone. The present knoll-like forms of some of these reefs are thought to result from later erosion, not from original deposition.

The fauna peculiar to the reef-facies is not readily defined. Crinoids, molluscs and brachiopods predominate and are often unusually large. Bryozoa are common but corals uncommon. Very occasional fossils, mainly goniatites, are diagnostic of age, but the chief elements of the fauna are common to the reef-facies, whatever its age.

The work of Hudson, Parkinson and others stresses the accumulation of great masses of reef-limestone along belts marginal to massifs and leads to the concept of a gradual outward passage, at any one horizon, of standard limestone into a composite reef-belt, which terminated in a steep slope on the edge of the basin and which was fringed in places by apron-reefs (Fig. 8).

Shirley and Horsfield do not find a gradual passage of standard limestone into reef in the Castleton area of North Derbyshire. Instead, they recognize extensive apron-reefs banked against the steep northern slopes of the standard limestone of the Derbyshire Massif. These slopes are interpreted as submarine cliffs, probably fault-scarps, at least 550 ft. high (see also p. 29).

Rhythmic sedimentation.—Whereas the rocks we have been considering—standard limestones of the massifs and mudstone and limestones of the basin—show no obvious pattern of repetition in their strata, their deposition was followed by a rhythmic type of sedimentation of limestone, mudstone and sandstone, which spread southwards into the area during the later part of the Lower Carboniferous period: and thereafter some form of rhythmic deposition became characteristic of the Upper Carboniferous rocks. This type of sedimentation appears to have been deltaic. The ' deltas ' advanced into the slowly subsiding area covered by the shallow Carboniferous sea, and their deposits were laid down in successive layers and slowly compacted.

The ' Yoredale Beds ' of the Askrigg Massif (p. 25) consist of rhythmic units with the following ascending sequence of phases: coal, limestone, shale, sandstone, seatearth. Certain units, especially the coal, are apt to be missing, and the limestones are the most constant members. The marine fauna of the limestones and shales includes crinoids, brachiopods and foraminifera, goniatites being very rare.

The Yoredale type of sedimentation did not spread south of the Askrigg Massif, where the ' culm ' phase continued to the end of Bowland Shales time. There succeeded a widespread phase of sand-deposition, followed throughout the Pennine region by the rhythmic sedimentation of the main mass of the Millstone Grit Series. Here the complete rhythmic unit contains the phases coal, marine mudstone, barren mudstone, sandstone (frequently a thick, coarse-grained bed), seatearth; and the limestone phase like that of the ' Yoredale Beds ' is seldom found. The fauna is chiefly goniatites and lamellibranchs, plant-debris becomes abundant, and in the higher part of the formation there appear non-marine lamellibranchs.

Coal Measures succeed the Millstone Grits with an almost imperceptible change in the pattern of the rhythmic units. Gradually the marine phase becomes subordinate to the non-marine lamellibranch phase, plant-debris and coal seams assume importance, sandstones become thinner and finer grained, and in general the units are thinner and less widespread.

IV. LOWER CARBONIFEROUS: CARBONIFEROUS LIMESTONE SERIES

MOST OF the Askrigg Massif consists of Lower Carboniferous rocks; and these rocks also cover considerable areas adjoining the coast at Morecambe Bay (Fig. 2). South of Skipton the Lower Carboniferous rocks are hidden beneath the Upper Carboniferous of the Central Pennines, but they emerge in the Peak District to form the limestone uplands of the Derbyshire Dome. Here they contain intrusive and extrusive igneous rocks.

Beneath the concealed coalfield in the East Midlands, Lower Carboniferous rocks have been found in oil borings, again with igneous rocks.

Zones of the Lower Carboniferous.—The labours of Phillips and others have made the rich and varied fauna of the ' Mountain Limestone ' familiar to early generations of geologists, though it is only within the present century that division into faunal zones has been accomplished. Garwood established a succession in north-west England in which prime importance was given to faunal bands. Vaughan made the Avon Gorge at Bristol the type-section of his ' Avonian ' series or stage, and by means of the corals and brachiopods established the zonal sequence shown in the table below (there is a tendency in some circles to regard the lowest zone, K, as being Devonian in age: see also p. 16). Sections in Belgium furnish the alternative name Dinantian, with the divisions shown in the table; these are based on the exposures at Tournai and in the cliffs along the River Meuse at Visé.

In the upper parts of the basin-facies of northern England the corals and brachiopods are not amenable to zonal use, and instead the goniatites and lamellibranchs have been employed to establish detailed subdivisions, the genus-zones *Beyrichoceras* (B), Lower *Posidonia* (P_1) and Upper *Posidonia* (P_2) having been given the status of stages. Agreement has not been reached on the correlation of the coral-brachiopod zones with the goniatite-lamellibranch stages, the suggested equation by Hudson, Parkinson and others of B_2 and P_1 with D_1 and D_2 having been challenged by Shirley and Horsfield, who claim that in Derbyshire the former lie unconformably on the latter. For convenience they are kept separate in the table below.

ZONAL DIVISIONS OF THE CARBONIFEROUS LIMESTONE SERIES (DINANTIAN)

UPPER CARBONIFEROUS LIMESTONE, UPPER AVONIAN, OR VISÉAN

Goniatite-Lamellibranch Stages—

UPPER *Posidonia* STAGE (P_2) (zones P_{2c}, P_{2b}, P_{2a})

Middle Bowland Shales of Craven; ' Limestone-shales ' (part) of Alport and Mixon; Pendleside Sandstone (part).

LOWER *Posidonia* STAGE (P_1) (zones P_{1d}, P_{1c}, P_{1b}, P_{1a})

Pendleside Sandstone (part).
Lower Bowland shales of Craven; ' Limestone-shales ' (part);
Nunlow Limestone of Derbyshire; Marginal facies of D_2 Limestones of massifs[1].

Beyrichoceras STAGE (B) (zones B_2, B_1)

Pendleside Limestone; Castleton Limestone of Derbyshire;
Marginal facies of D_1 and S_2 limestones of massifs[1].

[1] According to Hudson, Parkinson and others.

Coral-Brachiopod Zones—

Dibunophyllum ZONE (D) (Subzones D_3, D_2, D_1)
' Yoredale Beds ' (lower part); Great Scar Limestone of massif (part).
Parts of Draughton Limestone, Alport Limestone.

Seminula ZONE (S) (Subzones S_2, S_1)
Great Scar Limestone (part).
Parts of Draughton Limestone and Alport Limestone.
Skibeden Shales, Embsay Limestone (part).

UPPER *Syringothyris* ZONE (C_2)
Embsay Limestone (part), Cauldon Low Limestone.

LOWER CARBONIFEROUS LIMESTONE, LOWER AVONIAN, OR TOURNAISIAN

Coral-Brachiopod Zones—

LOWER *Syringothyris* ZONE (C_1)
Parts of Halton Shales and Haw Bank Limestone of Craven, *Solenopora* Beds of Weaver Hills and Eakring No. 146 Borehole.

Zaphrentis ZONE (Z) (Subzones Z_2, Z_1)
? Pinskey Gill Beds of Ravenstonedale.
Part of Haw Bank Limestone, and underlying mudstones and limestones of Skipton boring (part).

? *Cleistopora* ZONE (K)
Mudstones and limestones of Skipton boring (part).

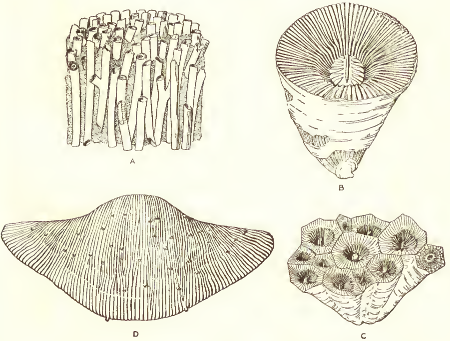


FIG. 9.—*Carboniferous Limestone fossils.*
(All natural size.)

A, *Lithostrotion junceum* (Fleming); **B,** *Dibunophyllum* cf. *turbinatum* (M'Coy); **C,** *Lonsdaleia floriformis* (Martin) forma *crassiconus* (M'Coy); **D,** *Productus* (*Gigantoproductus*) *latissimus* J. Sowerby.

Lower Carboniferous Limestone or Tournaisian

The lowest member of this division, the *Cleistopora* (K) Zone, is not known to be exposed in the Pennines; though a borehole near Skipton terminated in some 300 ft. of mudstones and limestones assigned by Hudson to this zone (see also Devonian, p. 16). The *Zaphrentis* Zone is thought to be represented locally in Ravenstonedale and in parts of Bowland Forest and Craven, but its absence from wide areas shows that much of the Pennine region remained land until nearly the end of Tournaisian time.

In the Ravenstonedale district the oldest Carboniferous rocks occur in Pinskey Gill as a thin series of sandstones, mudstones and dolomitic limestones which yield *Spirifer pinskeyensis*, *Lingula* and a few other fossils. These beds are not readily comparable with any part of the Avonian succession, but they are generally considered to represent some part of the *Zaphrentis* Zone. They underlie the Shap Conglomerate—unfossiliferous red sandstone and conglomerate consisting of local rocks—which, outside Pinskey Gill, forms the basement-bed of the Carboniferous. The highest Tournaisian beds in this district are impure, often dolomitic, limestones with shaly partings, which are best developed in the vicinity of Ravenstonedale, though small areas also occur in the Kendal and Arnside districts. One of the most distinctive features is the marked abundance in these limestones of calcareous algae, notably *Solenopora*. Rocks of Tournaisian age also occur in the Bowland Fells and the Craven lowlands and in the Dovedale and Cauldon Low areas at the southern end of the Pennines. In the Bowland Fells and at Skipton the Clitheroe and Haw Bank limestones yield fossils representing in part the *Zaphrentis* and *Syringothyris* zones. Two main subdivisions are represented. The lower group, the ' Chatburn Limestone ', consists of well-bedded limestone with thin shaly partings. *Syringopora* and *Zaphrentis* are the commonest corals, and the brachiopods include *Athyris*, *Chonetes* and *Productus*. Gastropods, including *Bellerophon* and *Naticopsis*, are a distinctive feature. The upper group, the ' Coplow Knoll Series ', consists of massive reef-limestones together with well-bedded crinoidal limestones and soft calcareous shales rich in *Fenestella* and crinoid remains. *Amplexus coralloides* is an abundant coral in the reef limestones, and the brachiopods include *Spirifer* and *Productus semireticulatus*. In the Dovedale and Cauldon Low districts of Derbyshire and Staffordshire the uppermost Tournaisian is represented by limestones which straddle the passage from massif to basin. In the Weaver Hills they include the *Solenopora* Beds (C_1), which are dolomitic mudstones and crinoidal limestones with shales, with the alga *Solenopora garwoodi*, which is also found in Eakring No. 146 Borehole. The lowest limestones in Gun Hill Boring (Fig. 13) are thought to be possibly Tournaisian, likewise some of the beds in Woodale Boring.

Upper Carboniferous Limestone or Viséan

Earth-movements of mid-Dinantian age have caused the Viséan rocks of Craven and Bowland Forest, though not of Derbyshire and Staffordshire, to rest unconformably on Tournaisian. The sea in Viséan times extended far and wide over both basins and massifs, and threw down an astonishingly diverse set of limestones, shales and sandstones. Different facies of the Viséan are well displayed in the several regions considered below.

The Fell Country

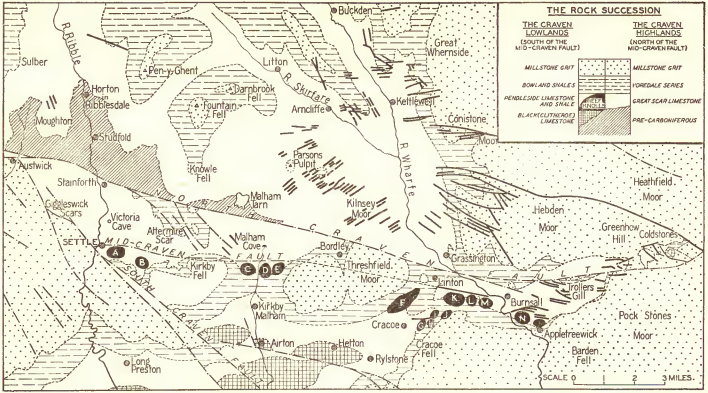
To the north of the Craven Faults two main groups are present—the Great Scar Limestone below and the ' Yoredale Beds ' above (Fig. 8). They represent deposition in shallow water over the Askrigg Massif, and remain to the present day substantially undisturbed by earth-movements. The lower group extends north-westwards into the Ravenstonedale and Kendal country; but both groups pass abruptly, at the Craven Fault-belt on the south, into the basin-facies of the Craven Lowlands (see below).

Great Scar Limestone Group.—The lowest Viséan beds in the Arnside, Kendal and Ravenstonedale districts consist of thick-bedded grey limestones often showing oolitic structure, with some calcareous grits in which are layers of false-bedded conglomerate known as the ' Brownber Pebble Bed '—a current-bedded deposit of quartz pebbles embedded in a coarse oolitic matrix. The commonest fossils are brachiopods of which *Spirifer furcatus* and *Productus rotundus* are noteworthy species.

A limestone charaeterized by the coral *Michelinia grandis* overlies this lower group and can be traced over a wide area. It is developed in the Arnside and Kendal districts along the north-eastern shores of Morecambe Bay, and also to the north-east of the Howgill Fells in the Ravenstonedale district. It is also recognized as far south as Settle, where it forms the lowest bed present in the Carboniferous succession. *Zaphrentis* and *Clisiophyllum* are characteristic corals in addition to the index-fossil *Michelinia grandis;* the brachiopods include *Daviesiella carinata* and *Stenoscisma* [*Camarophoria*].

To the south-east these beds become united with limestones in the lower part of the ' Yoredale Beds ' (Fig. 8), and the Great Scar Limestone forms a broad outcrop north of the Craven Faults in Kingsdale, Ribblesdale and Wharfedale, with inliers in Wensleydale, Semerdale and Bishopdale. Of ' standard limestone ' phase (p. 18) with occasional small reef-knolls, it yields a fauna referred to the divisions C_2, S and D_1; brachiopods include *Chonetes*, *Davidsonina* [*Cyrtina*] and *Productus;* corals, *Palaeosmilia* and *Nematophyllum;* and polyzoa and calcareous algae abound at some horizons. Certain faunal marker-bands are widespread, e.g. bands with *Davidsonina* [*Cyrtina*] *septosa*, *Lithostrotion arachnoideum* and *Girvanella*. The Great Scar Limestone is commonly a well-bedded, massive, pale-grey rock, and its shelf-like outcrops form the finest areas of ' karst ' landscape in Britain (Frontispiece, Plates IIIB, IV, V).

' *Yoredale Beds* '.—Although J. Phillips proposed the term ' Yoredale Series ' as a stratigraphical division (choosing Upper Wensleydale as the type-area), the name is now retained only for a particular facies of the Carboniferous which is found on and to the north of the Askrigg Massif: Dunham indeed, in a recent description of Carboniferous areas to the north, entirely discards the term. Almost the entire Dale country north of the Craven district is cut into ' Yoredale ' strata, which in the North Yorkshire area consist of six or seven rhythmic units (p. 20) aggregating over 1,000 ft. in thickness. Differential weathering of the many alternations of hard limestones and sandstones and soft shales gives rise to a characteristic topography of terraced slopes, and as these Yoredale strata remain almost undisturbed, other than a slight tilt to the east, each terrace and scarp generally extends throughout the whole length of a dale. The names of the limestones, e.g. the Hardraw Scar,



Prominent hills of reef-limestone are shown by distinctive letters as follows: A, High Hill; B, Scaleber; C, Burns Hill; D. Cawden; E. Wedber; F, Swinden; G, Skelterton; H, Carden; I, Butterhaw; J, Stebden; K, Elbolton; L. Thorpe Kail; M, Byra Bank; N, Hartlington Kail.

Thick black lines indicate mineral veins, and broken lines the main faults.

FIG. 10.—*Geological map of the Craven district.*

(For description, *see* p. v.) (A 7554)

A.—MALHAM COVE

(For description, *see* p. v.) (A 7560)

B.—'CLINTS' OR 'GRIKES' ABOVE MALHAM COVE

PLATE V

(For description, *see* p. v.)

(*Photo: G. Bingley*)

INGLEBOROUGH, SEEN FROM THE LIMESTONE PLATEAU

Simonstone, Middle, Undersett, and Main—in ascending order above the Great Scar—are local to the North Yorkshire dales.

The rhythm of deposition (see above, p. 20) is reflected in the faunal succession, which is essentially one of corals and brachiopods—goniatites being extremely rare—and is obviously controlled by lithology. The shale-faunas not only differ from those of the limestones, but also show variation amongst themselves according to lime-content. Faunal variations also occur in the limestones; usually coral bands are at the base and algal beds at the top. This area, and indeed the Yoredale country as a whole, has received from geologists much less attention than have others, and the faunal assemblages, as yet not thoroughly known, can only be given a D_{2-3} age. Correlation of the lower half of the 'Yoredale Beds' with the Upper Viséan of more southerly districts is based on the presence of the corals *Lonsdaleia*, *Dibunophyllum* and *Orionastraea*, and brachiopods such as *Productus pugilis* and *P. giganteus*.

Detailed relationship between the 'Yoredale Beds' and the Bowland Shales is not yet known, for there is a rarity of goniatites with firm specific identifications and clearly recognizable positions in the Yoredale sequence. However, the meagre finds are being gradually augmented, and a recent review by Dr. D. H. Rayner concludes that the junction of Stages P_2 and E_1 is a little above the Undersett Limestone (see Fig. 8); a conclusion with which most geologists would be disposed to agree.

The Craven District

Abrupt changes in the character of the Upper Avonian succession take place from north to south across the Craven Fault-belt, the rocks within this belt constituting a transition series between those on either side (Figs. 8, 10). It would appear that the Mid-Craven Fault, in particular, corresponds with a line of contemporaneous movement at the south margin of the Askrigg Massif—movement which strongly influenced Viséan sedimentation.

The complicated stratigraphy of this region has been described by Hudson and others. The Great Scar Limestone of the massif passes southwards across the Mid-Craven Fault into reef-limestones. These form conspicuous rounded hills in the vicinity of Malham, Cracoe and Burnsall (Fig. 10) but appear, nevertheless, to be 'flat reefs' and 'unbedded reefs' (p. 20) rather than 'knoll-reefs'. Much of their substance is unfossiliferous calcite-mudstone, but shelly limestone with characteristic reef-fauna occurs irregularly. 'Apron-reefs' are found in places on the outer slopes facing the basin, and in that direction the reef-facies passes rapidly into basin-facies.

Along the same line some part of the 'Yoredale Beds' must change into Bowland Shales, but the actual passage of one into the other is cut out by unconformity at the base of the Millstone Grit (Fig. 8).

South of the Askrigg Massif, in the area now occupied by the Craven Lowlands, sedimentation in what was, relatively, a basin produced the great mass of Viséan rocks shown on the right of Fig. 8. The lower beds are shales and argillaceous limestones with a scanty fauna of C, S and D_1 ages. The higher beds are dark mudstones with bands of limestone, with goniatites and lamellibranchs of P age; and these contain a sandstone and a limestone group—Nettleber Sandstone and Berwick Limestone—which are comparable with Harlow Hill Sandstone and Harrogate Roadstones in the badly-exposed Harrogate Anticline to the east.

Transgression of the Viséan sea onto the massif was marked by a succession of marginal reef-masses as shown in Fig. 8. Folding accompanied deposition at a number of periods.

Ribblesdale

Viséan or Upper Avonian rocks are well developed in this area. The lowest beds form the ' Salt Hill Knoll Series ' which includes bedded limestones, calcareous shales and reef-limestones. The reef-limestones form a series of conspicuous isolated hills, or knolls, which rise abruptly 200 to 300 ft. above the general level of the surrounding country. Fossils are frequently very abundant in the reef-limestones and include the brachiopods *Schizophoria, Pugnax* and *Productus semireticulatus*.

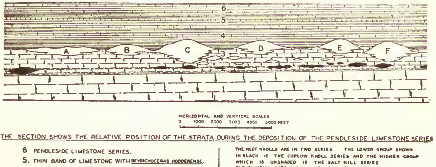


FIG. 11.—*Diagrammatic section illustrating mode of deposition of reef-knolls in the Clitheroe district.* (After Parkinson.)

The Knoll Series is succeeded by a thick group of beds known as ' Worston Shales '. These show wide variations in thickness, and wherever there is a local thickening of the underlying Salt Hill limestones there is a corresponding thinning of the overlying Worston Shales. The explanation appears to be that the knolls stood above the general level of the sea-floor during their formation, and the Worston Shales subsequently filled up the hollows in this uneven floor.

The highest Viséan beds in the Bowland Fells include the ' Pendleside Limestone Series ' below and the ' Lower Bowland Shales ' above. The former, which can be correlated with the Great Scar Limestone of the Fells district, consists of alternating shales and limestones. One of the most distinctive bands of limestone is that characterized by the cephalopod *Beyrichoceras hodderense*. The limestones in the upper part of the Pendleside Limestone Series are often crowded with crinoid ossicles, broken shells and coral fragments, and the intervening beds include unfossiliferous limestones and shales. *Lithostrotion arachnoideum* is a characteristic coral, and the brachiopods include *Chonetes* and *Productus*.

The Lower Bowland Shales are mainly dark shales with goniatites, but include a fine-grained sandstone known as the Pendleside Grit. In their lowest part the lamellibranch *Posidonia becheri* is a characteristic fossil.

Derbyshire and Staffordshire

In the Peak District of Derbyshire at least 1,500 ft. of Viséan limestones are exposed, and are underlain near Buxton by a further 900 ft. of limestones, of ages not yet determined, in the Woodale Borehole.

The inferred conditions of sedimentation are comparable with those in West Yorkshire, and the well-bedded standard limestones which are the commonest rock-type appear to have been deposited on a ' Derbyshire Massif ' with a (presumed) Pre-Cambrian ' basement ' found at the bottom of Woodale Borehole. The limestones are mainly massive and thick-bedded, and give rise to an elevated plateau intersected by deep dales of exquisite beauty. Those beds which are almost free from impurity are being actively quarried near Buxton, and there are large quarries in other parts of the outcrop.

Some beds are darker and shaly, e.g. the *Daviesiella* beds at the base of the exposed sequence; some are dolomitic, some cherty, and some are locally silicified. The sequence is interrupted by both intrusive and extrusive igneous rocks, and much of the limestone is heavily mineralized.

The coral-brachiopod zonal divisions C_2, S, D_1, D_2 are considered to be represented in the standard limestones, and there are certain faunal marker-bands, such as those with *Davidsonina* [*Cyrtina*] *septosa* and *Orionastraea placenta.*

Whereas the standard limestones contain occasional isolated reef-knolls, the margins of the massif are fringed with reef-limestones of uncommon interest. The origins of these reef-limestones, and especially their relations to the standard limestones, are matters of controversy. On the north, Shirley and Horsfield have mapped apron-reefs of B_2 and P ages—the Castleton and Nunlow Limestones—banked against cliffs of standard limestone of D_1 and D_2 ages. They recognize no lateral passage of standard limestone into these reefs, and find a skin of reef-limestone extending onto the high ground near the margin of the massif.

On the west and south-west, Parkinson, Prentice and others infer a lateral passage of standard limestone into marginal reef-belts of the Craven type (p. 27), which pass outwards into limestone and shale of basin facies. The B_2 and P_1 reefs of upper Dovedale contain much shelly limestone, and form spectacular crags such as Chrome Hill.

Viséan limestone of massif, or perhaps marginal, facies crops out in small inliers at Ashover and Crich on the east.

Rocks which are mainly of basin facies crop out in the south-west, where they include the limestones and shales of the Weaver Hills, Cauldon Low and the Manifold valley. The *Productus humerosus* beds (C_2) are developed in this region. The *Posidonia* stages are represented by shales with thin limestones and sandstones and beds of tuff. A good section is provided by the Gun Hill Boring near Mixon.

Deep borings at Alport and Edale in the Peak district have proved a similar succession. At Alport, limestones of S_2 and D_1 ages are overlain by very fossiliferous shales and limestones of B_2 and P ages. Muddy and calcareous tuffs are again found, and pillow-lavas occur close to the edge of the basin in a borehole at Hope.

Lower Carboniferous rocks were bored into below the exposed Coal Measures in Derbyshire in tests for oil—Hardstoft, Renishaw, Ironville, Ridgeway and others—made in the years 1918–21: but the cable-drilling then in vogue gave little information beyond the fact that limestone and igneous rocks were struck. More important results were obtained later in Nottinghamshire.

Nottinghamshire

Among the large number of oil borings recently drilled in the vicinity of Newark, several have penetrated the Carboniferous Limestone. The deepest well, No. 146 at Dukes Wood, Eakring, reached Lower Carboniferous at 2,570 ft. from surface and proved nearly 3,000 ft. of limestones with reddish conglomerates and sandstones, and with igneous rocks, referred to subzones C_1 to D_2. Below this were about 1,660 ft. of reddish conglomerates, possibly of Devonian age (p. 16). Other boreholes, drilled short distances into the Lower Carboniferous, appear to show that limestone of ' massif ' type and generally of *Dibunophyllum* age underlies the Upper Carboniferous over a wide area extending into Yorkshire and Lincolnshire. Shales and limestones of ' basin ' facies have, however, been encountered in boreholes near Nottingham, south of the area here described.

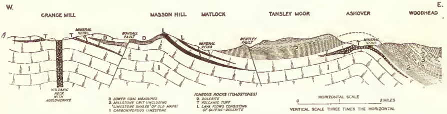


FIG. 12.—*Section across the eastern part of the Derbyshire Dome, illustrating the occurrence of toadstones.*

ASSOCIATED IGNEOUS ROCKS

Igneous rocks of basaltic types occur in the Lower Carboniferous of Derbyshire, Nottinghamshire and Staffordshire. At outcrop their dark colour is conspicuous among the pale limestones, though from their relatively rapid weathering they usually lie in depressions. In the mining field of Derbyshire they are generally called ' toadstones ', and have proved almost impervious alike to ascending ore-solutions and descending water. They are of two chief types: contemporaneous vents, lavas, and tuffs; and later intrusions, mainly sills.

The contemporaneous rocks are found chiefly in the neighbourhoods of Millers Dale, Matlock and Tissington; also in Staffordshire and under the Derbyshire and Nottinghamshire Coalfield. Vents, of which several are recognized at outcrop, are filled mainly with agglomerate, partly with basalt. Lavas are mostly olivine-basalts, often porphyritic: two main flows are widespread round Millers Dale and Matlock, but several flows occur in Millclose Mine, north of Matlock. An analcime-basalt occurs at Calton Hill. Tuffs are usually greenish altered rocks that turn brown on weathering, and consist of glassy lapilli in a matrix of volcanic dust and calcite, with fragments of limestone and other rocks. Tuffs and ashy sediments are common in rocks of the *Posidonia* stages in the west and north of the Derbyshire Dome, and at Hope, close to the edge of the massif, pillow-lavas are associated with tuffs and ashy limestones near the top of the Lower Carboniferous.

Intrusive sills of dolerite occur in various places. Thick masses which are probably sills have been cut in borings under the Nottinghamshire Coalfield, where they are also common in the overlying Millstone Grit and Coal Measures; they include olivine-dolerites, analcime-dolerites and picrites.

MINERAL VEINS

Ores of lead and zinc, with fluorspar, barytes and other minerals, occur in veins, flats and replacement-bodies, chiefly in the Carboniferous Limestone but to a small extent in the Millstone Grit. They have been worked in two main districts: (1) The Yorkshire Fells (Askrigg Massif), chiefly in Upper Swaledale, and in the Craven country (Fig. 10); (2) The Derbyshire Hills and inliers of limestone east of them at Ashover and Crich. Much of the more accessible lead and zinc ore has been removed, and recently fluorspar and barytes have been the chief products.

An isolated occurrence of copper ore was formerly mined at Ecton on the west side of the Derbyshire Hills. Fluorspar and barytes were found in the top of the Carboniferous Limestone in the Eakring oilfield. For further details of mineral deposits see p. 80.

V. UPPER CARBONIFEROUS:

MILLSTONE GRIT SERIES

THE Millstone Grit Series is a group of mudstones and shales with beds of sandstone and grit, separating the Carboniferous Limestone Series from the Coal Measures. In the Yorkshire Fells there are outliers of grit capping conspicuous hills of 'Yoredale Beds' such as Ingleborough, Whernside and Penyghent, which rise abruptly above the plateau of the Great Scar Limestone (Plate V). In West Yorkshire the outcrop extends in a broad belt from Richmond to the outskirts of Leeds and Bradford, and narrows down the ridge of the Central Pennines to the Peak District (Fig. 13), whence it almost encircles the limestone hills of Derbyshire. In Lancashire the two main areas are the Lancaster Fells and the Rossendale Hills, with a narrow subsidiary area stretching from Colne to Blackburn.

Within the region under review the Millstone Grit Series shows its fullest development in Britain. But the complete series, at least 6,000 ft. thick in the Skipton and Burnley country, suffers irregular attenuation in a southerly direction, and disappears completely in the Midlands not far beyond the southern confines of the region (Fig. 13).

Sedimentation and marine bands.—The inferred conditions of sedimentation are mentioned on p. 20. In general, these were more uniform than in Dinantian times, and only in the lower beds on the Askrigg Massif and in the Craven country is there strong contrast between facies. Here the Craven Fault-belt continued into Namurian times to separate a 'Yoredale' environment on the north from a 'Bowland Shales' environment on the south (pp. 20, 27), until sedimentation of the Grassington Grit covered both areas.

After the gigantic invasion of the Grassington, Pendle or Skipton Moor Grit had spread its sands and gravels far and wide over the site of northern England, a series of deposits followed in which we see the gradual emergence of a rhythmic pattern of sedimentation which by R_1 times had become firmly established in the north and was spreading into the Midlands. Its rhythmic pattern shows two particular characteristics: the common appearance of a thick sandstone phase, and the general confinement of the marine phase to a thin 'marine band' at the base of the unit, i.e. immediately above the thin coal or seatearth which commonly succeeds the sandstone phase.

The typical marine band is a dark grey mudstone with flattened shells, chiefly of cephalopods and lamellibranchs but also with brachiopods, gastropods and other animal remains, and sometimes with large nodules of argillaceous limestone—'bullions'—containing undistorted shells. Occasionally, however, we find beds of silty or argillaceous limestone forming all or part of the marine band, and these are commonest in the north. They show, in fact, the beginning of the transition to the Yoredale facies of the Askrigg Massif.

Among cephalopods the goniatites are most abundant, and have proved to be zone-fossils of the greatest value. Although uncrushed specimens exhibiting suture-line and shape of shell are relatively uncommon, the shell-ornament still visible in flattened goniatites has, under W. S. Bisat's technique, been made a reliable aid to specific identification. The narrow time-range of many of the species so identified has enabled palaeontologists to subdivide the Millstone Grit Series into six stages and sixteen zones.

CLASSIFICATION

Early attempts to classify the Millstone Grit aimed at establishing continuity of prominent beds of gritstone from place to place, and led to extreme confusion: for instance, false correlatives of the Kinderscout Grit of Derbyshire, then considered the lowest grit in the formation, were found among the Skipton

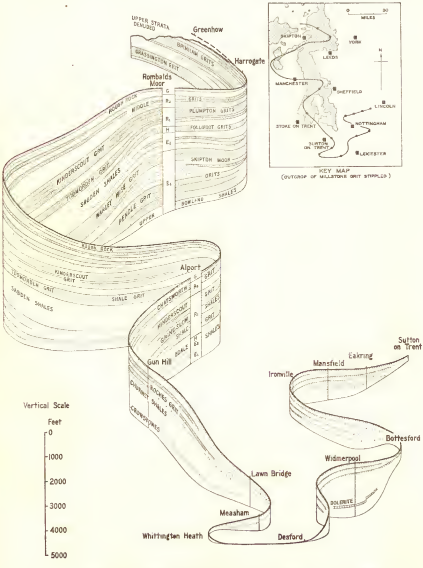


FIG. 13.—*Vertical and lateral variations in the Millstone Grit, illustrated by a ribbon-diagram.*

Moor Grits 3,000 ft. lower. This obsolete classification, using the terminology ' First ' to ' Fourth ' Grit (from above downwards), or using local names without palaeontological control, is still found on certain Old-Series maps of the Geological Survey, but it is being replaced on new maps by the classification based on goniatite-faunas.

Zoning of the Millstone Grit has been effected mainly by W. S. Bisat who, in 1924, erected the genus-zones *Eumorphoceras* (E), *Homoceras* (H), *Reticuloceras* (R) and *Gastrioceras* (G), and divided these into a number of species-zones. He amplified his earlier work in 1928, subdividing and naming his genus-zones—E_1 Grassingtonian, E_2 Lower Sabdenian, H Upper Sabdenian, R_1 Kinderscoutian, R_2 Marsdenian, G Halifaxian—and making several new species-zones. In 1942 Stephens and others classed Bisat's subdivided genus-zones as ' stages ', equating them with lithological units as in the table below: and this practice is followed in recent Geological Survey maps and in the memoirs, ' Geology of the District North and East of Leeds ', 1950, and ' Geology of the Country between Bradford and Skipton ', 1953. A set of stage-names, differing in some respects from the genus-zones of Bisat, was introduced by Hudson in 1945: i.e. E_1 Pendleian, E_2 Arnsbergian, H Sabdenian, R_1 Kinderscoutian, R_2 Marsdenian, G_1 Yeadonian (including only the beds up to the base of the Coal Measures).

Various refinements in the employment and delimitation of species-zones have been put forward from time to time, and agreement on these minor divisions is not entirely complete. The recent usage of the Geological Survey is as follows:—

STAGES AND ZONES OF THE MILLSTONE GRIT
(in downward succession)

	Approx. max. thickness in ft.
STAGE G (*Gastrioceras*): ROUGH ROCK GROUP .. .. Zones (from above downwards).—*G. cumbriense*, *G. cancellatum* (including *G. rurae*)	375
STAGE R_2 (Upper *Reticuloceras*): MIDDLE GRIT GROUP .. .. Zones.—*R. reticulatum* mut. *superbilingue*, mut. *bilingue*, mut. *gracile*	525
STAGE R_1 (Lower *Reticuloceras*): KINDERSCOUT GRIT GROUP .. .. Zones.—*R. reticulatum reticvlatum*, *R. eoreticulatum*, *R. circumplicatile*	1,150
STAGE H (*Homoceras*): MIDDLETON GRIT GROUP (or Upper Sabden Shales) .. Zones.—*H. eostriolatum*, *H. beyrichianum*, *H. subglobosum*, *Nuculoceras nuculum* and *Cravenoceratoides fragilis*	500
STAGE E_2 (Upper *Eumorphoceras*): SILSDEN MOOR GRIT GROUP (or Lower Sabden Shales) .. .. Zones.—*Cravenoceratoides stellarum*, *C. nitidus*, *Eumorphoceras bisulcatum* and *Cravenoceras cowlingense*	1,200
STAGE E_1 (Lower *Eumorphoceras*): SKIPTON MOOR GRIT GROUP (Pendle, Warley Wise and Grassington Grits) and UPPER BOWLAND SHALES .. .. .. Zones.—*Cravenoceras malhamense* (E_{1c}), *Eumorphoceras pseudobilingue* (E_{1b}), *Cravenoceras leion* (E_{1a})	2,400

The base of the Millstone Grit Series.—W. S. Bisat has taken the dividing line between Upper and Lower Carboniferous in the ' basin ' facies at that level where, in a broad sense, the genus *Goniatites* is replaced upwards by the genera *Eumorphoceras* and *Cravenoceras*. Within this facies, the recent practice of the Geological Survey has been to use this dividing line, or the nearest ' mappable ' horizon to it, as the base of the Millstone Grit, thus giving the term Millstone

Grit Series a similar meaning to ' Namurian ' as generally understood in Western Europe. In the Clitheroe and Skipton country this horizon is at the base of the Upper Bowland Shales; and on the Askrigg Massif it appears to be close to the Main and Undersett limestones of the ' Yoredale Beds ' (p. 27 and Fig. 8).

In some areas of ' basin ' sedimentation, e.g. parts of the Clitheroe and Craven country and of the Peak District, the lowest horizons of the Millstone Grit rest conformably on the Lower Carboniferous, and the palaeontological principles outlined above have been applied in their identification; but northwards across the Craven Fault-belt, and southwards onto the edge of the Derbyshire Massif, the Millstone Grit Series overlaps and is strongly unconformable on the Carboniferous Limestone (Figs. 8, 13). Thus in the Craven and Greenhow country various horizons of the Upper Bowland Shales and Grassington Grit lie on and around the fault-scarped knolls of Viséan reef-limestone and on the lower ' Yoredale Beds '. A similar ' pre-Namurian topography ' was buried beneath overlapping Edale Shales in the Peak district: and in both areas it is now being uncovered by erosion.

STRATIGRAPHY

Notwithstanding lateral changes in lithology, the stratigraphical divisions tabulated on p. 34 are recognized by their fauna throughout the range of the Millstone Grit (except where the lower beds are overlapped as described below, and in the extreme north of the district where deposits of ages R and G have not been recognized). The characters of these divisions are, briefly, as follows:—

Upper Bowland Shales and Skipton Moor Grit Group (Stage E_1).—On both sides of Ribblesdale there is a conformable passage from the Dinantian into the Namurian. The south side includes Pendle, the type-area of the ' Pendleian ', the north side embraces the Bowland Trough from which the Bowland Shales have derived their name. The passage occurs within the Bowland Shales. Lithologically Bowland Shales consist of well-bedded laminated black shales (displaying on weathering irregular rusty staining) with several interbedded thin marine bands. The latter consist of limy shales with thin-bedded argillaceous limestones or bullions of an iron-calcium carbonate rock lying at constant horizons. Lithologically the Bowland Shales of Bowland are indivisible, and the ' Upper Bowland Shales ' is an arbitrary subdivision about 400 ft. thick, defined as lying between two marine bands. At first their base was taken at the incoming of *Eumorphoceras pseudobilingue*, subsequently modified in 1930 to the association of *Cravenoceras leion* and *E. pseudobilingue* (earliest form). Several early species of *Eumorphoceras* are known from this general level, including *E. tornquisti*. The top of the Upper Bowland Shales is marked by a persistent argillaceous limestone which contains *C. malhamense*. Sandy shales to shaly sandstones overlie this limestone and quickly pass upwards into massive sandstone.

In Ribblesdale the massive sandstones are termed Pendle Grit and, near Preston, Wilpshire or Lower Wilpshire Grit. Although termed grits they are thick massive sandstones separated by subordinate sandy shales. They vary in thickness between 800 ft. and 1,600 ft., and throughout this great thickness have yielded no fossils except obscure plant-remains.

The Pendle Grit is separated by sandy shales and flaggy sandstones from the Warley Wise Grit. This latter is a coarse grit containing scattered quartz and quartzite pebbles as well as bands of these pebbles; *Calamites* stems are numerous in places and plant-debris also occurs in the thin shale partings which, not infrequently, have been eroded to form lines of shale pellets. On the south side of Ribblesdale the Warley Wise Grit outcrops from near Preston to Lothersdale, and on the north side it occupies considerable areas on the Lancaster Fells.

In the Craven country, as already stated, the Upper Bowland Shales are overlapped northwards against the Carboniferous Limestone of the Askrigg Massif. On the massif their age-equivalents appear to be the upper part of the ' Yoredale Beds ' (Fig. 8), which in like manner are overlapped southwards towards the margin of the massif. Thus no complete passage has been seen from the one facies to the other, though certain thin beds of limestone in the southern facies have been observed to thicken and take on a ' Yoredale ' appearance as they are followed towards the massif.

The Skipton Moor Grits comprise the Pendle Grit and the Warley Wise Grit (which is probably the Grassington Grit), and also the Harrogate Grits. They are a composite group of gritstones and mudstones up to 2,100 ft. thick, with obscure plant-debris but apparently no other fossils; some beds are very coarse-grained, with cobbles up to 3 in. The grits contain occasional seams of poor coal such as the Bradley Coal. Of north-eastern origin, the Skipton Moor Grits crop out over great areas north of the Lancashire and Yorkshire coalfields, but they are barely represented in the southern Pennines (Fig. 13). Here, in Derbyshire and Staffordshire, the E_1 strata are shales with thin beds of Crowstones—quartzose siltstones toughly cemented with carbonates. The shales above the crowstones contain an abundant fauna with *Eumorphoceras pseudobilingue* and species of *Posidonia*.

Silsden Moor Grit Group (Stage E_2).—The base of the Stage is marked by a widespread marine horizon, the Warley Wise or Edge Marine Band, in which the characteristic fossil is *Cravenoceras cowlingense*. In the Lancaster Fells the lower part of the stage is represented by sandstones with subordinate bands of shale to a thickness of about 800 ft. This arenaceous series ends with the ganister of the Caton Coal Seam which is followed by the Caton Shales. These fossiliferous shales, about 150 ft. thick, yield brachiopods and goniatites of zonal value including *Cravenoceratoides bisati*, *Ct. nitidus*, *Ct. stellarum*, and *Cravenoceras holmesi*.

To the south of Ribblesdale, although the beds are not well exposed, it is apparent that they are dominantly argillaceous. They represent the lower part of the Sabden Shales.

Near Skipton and Harrogate the Group consists chiefly of mudstone, but with the prominent Almscliff or Marchup Grit and other thinner beds of sandstone. The sandstones die out southwards, but shales of this age crop out in the Central Pennines near Todmorden and Hebden Bridge. In North Derbyshire they include part of the Edale Shales (Fig. 13), here very rich in goniatites. In Staffordshire they are represented by the lower beds of the Churnet Shales, with beds of sandstone, the Morredge Grits. Similar shales with E_2 goniatites have been found in boreholes at Hathern and Lawn Bridge, south of the area here described (but see Fig. 13); in some intermediate localities, however, beds of this stage are overlapped.

Middleton Grit Group (Stage H).—The rocks referred to this stage include a group of alternating shales and gritstones ranging up to 500 ft. in thickness in upper Wharfedale, but much thinner in more southerly areas.

In the neighbourhood of Masham the lower part of the stage consists mainly of variable sandstones and shales. In the Fell country to the west these include the Shunner Fell Top Grit. Farther south two prominent beds of gritstone, the Lower and Upper Follifoot Grits, make strong features in Upper Nidderdale. These are represented in the upper parts of Wharfedale and Airedale by the Middleton and Brocka Bank Grits respectively. Marine bands occur in the intervening shales, the fossils including *Homoceras subglobosum*, *H. diadema* and *H. beyrichianum.*

Between Skipton and Blackburn these beds are largely dark shales and sandstones, but only in isolated exposures can they be seen. Fossiliferous shales belonging to the lower part of the group crop out in the vicinity of Cowling, and a succession of marine bands in the upper beds occurs at Rough Lee, near Colne. Fossils include *Homoceras subglobosum*, *H. diadema* and *H. proteum.* The same horizons crop out in the landslipped slopes near Todmorden on the borders of Yorkshire and Lancashire.

It has already been indicated (p. 36) that the lower part of the Edale Shales in North Derbyshire is of E_1 age. The upper part includes Stages E_2 and H (with goniatites as above) and the lower part of R_1. In Staffordshire the *Homoceras* age is presumably represented in the Churnet Shales, the stratigraphy of which has not yet been worked out in detail. Beds of this stage have not been positively identified in more southerly areas, nor in the Nottinghamshire oilfields.

Kinderscout Grit Group (Stage R_1).—In the Peak District this group reaches its maximum thickness of about 1,500 ft. In all areas the lower part consists largely of shale, with some thin bands of limestone in North Yorkshire: the upper part embraces the Kinderscout Grit and associated sandstones, which extend from the Yorkshire Fells to the Derbyshire Hills; these are mainly thickly-bedded and coarse pebbly gritstones, which give rise to rugged scenery along the borders of Lancashire, Yorkshire and Derbyshire.

North of Wharfedale the lower part of this group includes the Cayton Gill Beds, which extend for a distance of twenty-four miles from Masham Moor and Nidderdale to the Washburn valley, but appear to die out farther south. They are sandy mudstones and siltstones, with abundant moulds of lamellibranchs and of brachiopods such as *Chonetes, Spirifer* and *Productus.* In the face of Otley Chevin the similar, but stratigraphically higher, Otley Shell Bed contains a profuse fauna including spines of the sponge *Hyalostelia* and new species of trilobites.

Between Colne and Blackburn the lower part of this group consists mainly of shale with a band of sandstone up to 450 ft. thick in places. Characteristic species of goniatites such as *Reticuloceras eoreticulatum*, *R. circumplicatile* and *R. umbilicatum* occur in the intervening shales at Samlesbury Bottoms four miles west of Blackburn, and at Rough Lee to the west of Colne. Similar beds are seen in the deep ' cloughs ' below the scarp of the Kinderscout Grit between Todmorden, Keighley and Hebden Bridge on the borders of Lancashire and Yorkshire, with fossiliferous bands yielding *Reticuloceras inconstans*, *R. reticulatum* and *Homoceras striolatum.*

In North Derbyshire the upper part of the Edale Shales yields similar

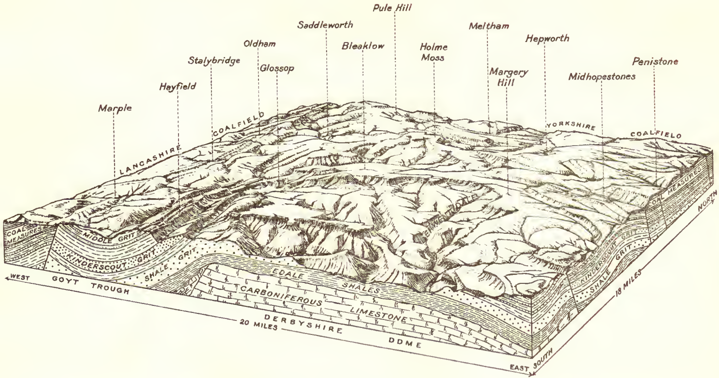


FIG. 14.—*Block diagram of the Peak District.*

Illustrating the characteristic topography formed by the Millstone Grit and, in generalized form, the relationship of the Millstone Grit to the Carboniferous Limestone.

goniatites. Shales of the same age lie close above the Carboniferous Limestone at Ashover, and near Matlock and Crich; also in the oil-wells at Eakring and, probably, Caunton and Kelham Hills.

In the upper part of the Kinderscout Grit Group thick beds of sandstone, though absent in the extreme north around Clapham, are conspicuous in most of the more southerly regions. In mid-Wharfedale and Airedale they include massive, coarse-grained beds variously called Addingham Edge, Earl Crag, Bramhope, Brimham and Plumpton Grits. South of Airedale there are two conspicuous groups of sandstones: an upper one, the Kinderscout Grit, sometimes divided, on the basis of intercalated shales, into Upper and Lower divisions; and a lower and finer-grained Todmorden or Shale Grit (with basal Mam Tor Sandstone in North Derbyshire), the thickness of the intervening Grindslow Shales being about 300 ft. These divisions extend into the Peak District where they are of great thickness (Fig. 13) and are splendidly displayed in deeply-dissected moorlands (Fig. 14). Southwards, along the flanks of the Derbyshire Massif, attenuation reduces them to insignificant thicknesses; and they peter out altogether in Staffordshire where the R_1 Stage is represented by part of the Churnet Shales.

Middle Grit Group (Stage R_2).—The traditional name ' Middle Grits ' derives from the time when the underlying Kinderscout Grit was considered to be the basal member of the Millstone Grit Series. The group, though of no great thickness, generally contains prominent sandstones; these are commonly overlain by fireclays or ganisters, and seams of coal are sometimes conspicuous. The several marine bands are well developed and are chiefly notable for a series of mutations of the goniatite *Reticuloceras reticulatum*, in which the shell-ornament shows progressive variation in the successive bands. The following ascending sequence is recognized by W. S. Bisat: mutation early α, α (*gracile*), late α, early β, β (*bilingue*), late β, early γ (*metabilingue*), γ (*superbilingue*). These mutations cause the marine bands, which are of great lateral extent, to be extremely valuable for correlation; and by their aid the succession of Middle Grits has become known in detail throughout the area (Fig. 13). Other fossils in these marine bands include the goniatites *Anthracoceras* and *Dimorphoceras* and nautiloids such as ' *Orthoceras* ' and *Metacoceras*, lamellibranchs such as *Dunbarella* and *Posidoniella*, and Productid brachiopods. The mut. α marine band also contains spicules of a sponge, probably *Hyalostelia* as in the Otley Shell Bed (p. 37). Anchoring spines and spicules of *Hyalostelia* also occur in the ' Bluestone ', a bed of hard siltstone lying above the mut. β band in the Keighley district of West Yorkshire.

Non-marine lamellibranchs, familiar in the overlying stage and in the Coal Measures, appear for the first time, so far as is known, a few feet above the mut. γ (*superbilingue*) band in West Yorkshire. They include *Carbonicola deansi* and *C. lenicurvata.*

In the Ingleton district the Middle Grit Group is represented mainly by shales, but to the south there appear several beds of sandstone, and the total thickness increases to 500 ft. in Airedale and Wharfedale and to over 600 ft. along the borders of Lancashire and Yorkshire. Here the group reaches its fullest development and includes several thick beds of gritstone, the most prominent being the Pule Hill (Fletcher Bank, Gorpley, Midgley, Revidge) Grit. In Staffordshire a coarse gritstone underlies the mut. γ marine band

and forms spectacular crags at The Roches. The uppermost sandstone of the group, the Holcombe Brook Grit or Huddersfield White Rock, crops out over a wide area between Wharfedale and the Southern Pennines. Fine-grained in the north, it becomes coarse in the south, and as the Rivelin or Chatsworth Grit on the east side of the Derbyshire Hills and the Shining Tor Grit on the west, stands out in abrupt ' edges '.

Rough Rock Group (lower part of Stage G).—This group comprises a thick shale series overlain by a bed of sandstone, the Rough Rock. It consists of measures closely resembling, and without palaeontological control indistinguishable from, the overlying Coal Measures. Three marine bands are known,

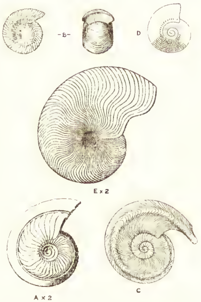


FIG. 15.—*Upper Carboniferous goniatites.*

(Natural size except where stated.)

A, *Eumorphoceras bisulcatum* Girty, Millstone Grit, Stage E_2; **B,** *Homoceras beyrichianum* (Haug), two views, Millstone Grit, Stage H; **C,** *Reticuloceras reticulatum* (Phillips), mut. *superbilingue* Bisat=mut. γ Bisat, Millstone Grit, Stage R_2, diagrammatic reconstruction; **D,** *Gastrioceras cancellatum* Bisat, Millstone Grit, Stage G, diagrammatic reconstruction; **E,** *Homoceratoides jacksoni* Bisat, Coal Measures, Stage A.

and non-marine lamellibranchs also occur, though not so commonly as in the Coal Measures. *Gastrioceras* is the dominant goniatite-genus, but the γ mutation of *Reticuloceras reticulatum* also occurs in the lowest zone.

Immediately overlying the top sandstone of the Middle Grit Group there is, in parts of the Southern Pennines, a coal or group of coals which has been worked locally, as in the vicinity of Holcombe Brook, Lancashire. Ganister and fireclay is also prominent at this horizon. Two marine bands are widespread in the overlying strata, a lower with *Gastrioceras cancellatum* and a higher with *G. cumbriense*. In parts of West Yorkshire a third band, with *Anthracoceras*, lies close under the Rough Rock. The fauna of the two lower bands also includes crinoid ossicles and fish-debris, brachiopods such as *Lingula* and *Chonetes* though *Productus* is no longer found, and lamellibranchs such as *Dunbarella* and *Posidoniella;* the small shell *Aviculopecten* cf. *losseni* has a local development in the *G. cumbriense* band.

Non-marine lamellibranchs occur above and just below the *G. cancellatum* band, and include the species *Carbonicola fallax, C. lenicurvata, C. pseudacuta,* and *Anthraconaia bellula.*

In the thick shale series underlying the Rough Rock there is, in the Rossendale Hills, a development of hard, well-bedded flaggy sandstones known as Haslingden Flags, which has been extensively quarried for paving stones.

The Rough Rock is, in most mid-Pennine areas, a rather uniform bed of coarse gritstone with flaggy lower beds known as Rough Rock Flags. In East Lancashire a workable seam of coal, the Sandrock Mine, occurs about midway in the main mass of gritstone. In the south the Rough Rock becomes thinner and fine-grained, and it is absent from parts of Derbyshire and Lancashire. It is present, though often very thin, in the oilfields of Nottinghamshire.

ASSOCIATED IGNEOUS ROCKS

These are confined to the ' concealed ' area on the south-east of the Pennines, where they have been discovered in test-borings for oil. Both olivine-dolerites and analcime-dolerites occur and, to judge by similar rocks in the Coal Measures (p. 58), are probably sill-like intrusions. Ashy sediments have been detected in a number of Nottinghamshire boreholes, apparently not far from the base of the Rough Rock Group.

VI. UPPER CARBONIFEROUS: COAL MEASURES

WITHIN the Pennines and Adjacent Areas are included two of the most important British coalfields. To the west lies that of Lancashire and Cheshire, cropping out in a distorted triangle; to the east that of Yorkshire and the East Midlands, partly exposed and partly concealed and with a proved area of at least 3,000 square miles. There is a small isolated coalfield at Ingleton in north-west Yorkshire, and still smaller outliers lie on the moors west and south-west of Buxton.

In the Pennine region the Coal Measures rest conformably on Millstone Grit, which their lower beds closely resemble. But the bulk of the Coal Measures are of somewhat different character from the Millstone Grit: rhythmic deposition is still apparent, but sandstones are thinner and finer grained; marine bands are uncommon, non-marine shell-beds very common; plant-debris is ubiquitous and seams of coal are thicker and more abundant. It seems that the subsiding area of deposition became silted up at frequent intervals to give rise to extensive flats at sea-level: vegetation colonized these flats and formed dense forests; the continuing subsidence drowned these forests and entombed their bulky residues (which subsequently were converted into coal seams) under fresh deposits of deltaic mud which again built up to sea-level. Periodicity in deposition continued until 3,000 to 4,000 ft. of measures with numerous workable coals had accumulated. Then conditions changed, the clastic sediments of the delta reached sea-level only occasionally and then were quickly overwhelmed. Thus were deposited some 1,000 ft. of measures with only occasional thin coals, and with freshwater limestones in their uppermost parts. Some of these measures now display a red coloration, especially in Nottinghamshire and Lincolnshire where 'Red Beds' overlie the productive Coal Measures in large areas of the Concealed Coalfield.

Eventually the region was uplifted and folded and the Coal Measures were denuded into the separate fields we see today.

Much-generalized sections of the measures in the chief coalfields are shown in Fig. 16. Here are indicated most of the marine bands, most of the major coals, and a few of the sandstones.

Sedimentation and lithology.—The rhythmic character of the sedimentation noticed in the Millstone Grit persists throughout the productive Coal Measures, but in these the persistent elements of the rhythm are the coal seam and its seatearth. The coal seams vary in thickness between a thin film and 14 ft., with most falling within the limits of 2 to 6 ft. They are classified as bituminous coals with volatiles ranging from 30 per cent to 46 per cent, but occasional seams of cannel coal also occur with volatiles of 40 per cent to 54 per cent.

Notwithstanding many exceptions it may be stated as a generality that the clastic sediments which occur between the coal seams become more arenaceous and less argillaceous in upward succession. The clastic sediments, however, are noted for their variability. The distance between seams or seatearths is variable, with perhaps 30 ft. as a rough average, and the upward sequence between seams is variable although in a general way mudstones succeed the coal and are overlain by arenaceous measures—siltstones, sandstones or grits—and followed by fireclay or ganister. Sandstones, however, alter laterally

(For description, *see* p. v.) HIGH TOR MATLOCK (*Photo: L.M.S. Railway*)

(For description, *see* p. v)

A.—THE WINNATS, CASTLETON, DERBYSHIRE

(For description *see* p. v) (*Photo: L.M.S. Railway*)

B—MAM TOR, CASTLETON, DERBYSHIRE

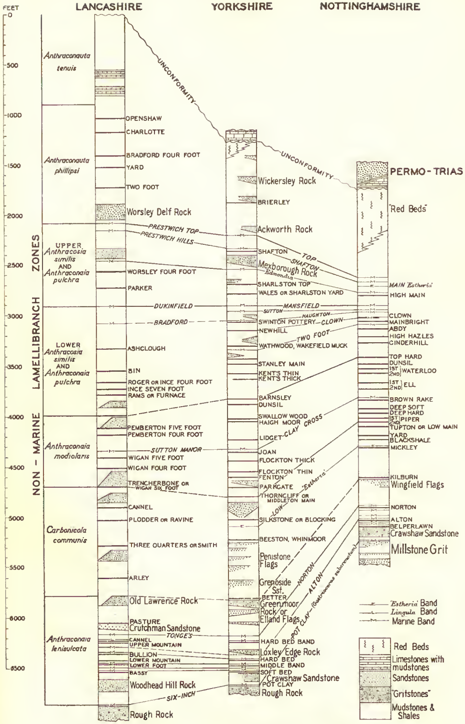


FIG. 16.—*Vertical sections of the Coal Measures, showing zones.*
(N.B. The Prestwich Hills Marine Band is more generally known as the Lower Sankey).

through laminated siltstones into mudstones and vice versa. Nevertheless it is not an uncommon occurrence for a sandstone to lie directly above a coal seam.

Except for certain coarse gritstones which are conspicuous by their very rarity, the sandstones are usually fine-grained. They are wedge-bedded and lenticular, and are apt to ' channel ' the underlying measures in ' washouts '. Individual beds are, on the whole, more persistent in the lower measures.

Seatearths vary between soft carbonaceous fireclays and hard ganisters. In them the ramifying rhizomes and rootlets of *Stigmaria* are conspicuous.

Shell-bands, when present, tend to occur above the coals. The less frequent type is the band with marine or ' pene-marine ' shells, seventeen of which are known in this region. The more frequent type is the non-marine lamellibranch band—the ' mussel band ' of the miner. These latter bands are calcitic in varying degree, and in the highest beds of the Coal Measures shells are found in freshwater lagoonal limestones.

In the productive Coal Measures, however, ferrous carbonate in the form of sideritic clayband and blackband ironstones is the dominant carbonate. The former occurs principally in mudstones and fireclays but is also found in siltstones and sandstones. The latter occurs only occasionally and then in intimate association with the upper part of a coal seam.

Fauna and flora.—Most of the animal-remains are confined to the mudstones close above coals or seatearths, and they tend to occur in the following upward sequence of phases: dark mudstone or shale with fish-remains, occasionally with non-marine shells or *Euestheria*; marine mudstone; mudstone with non-marine lamellibranchs, occasionally with *Euestheria* in the lower part. These phases are seldom all present above any one coal or seatearth, and sometimes only the non-marine phase, sometimes no fossiliferous phase at all, is found.

The fauna of the marine bands is generally remarkable for the abundance of *Lingula mytilloides*, a fossil which often characterizes ' *Lingula* bands ' to the exclusion of other, more definitely marine, shells. But several bands contain a fuller fauna: other brachiopods, and lamellibranchs such as *Dunbarella* and *Myalina*; goniatites including *Gastrioceras* in the lower part of the measures and *Anthracoceras* in the higher; nautiloids, gastropods and foraminifera: and the Clay Cross and Mansfield bands have yielded faunas numbering respectively 40 and 80 species.

Non-marine fossils include the familiar lamellibranchs *Carbonicola*, *Anthracosia*, *Anthracosphaerium*, *Anthraconaia*, *Anthraconauta* and *Naiadites;* small crustacea such as the ostracods *Geisina* and *Carbonita*, and the branchiopods *Euestheria* and *Estheriella* (these especially in the higher parts of the Coal Measures), and larger arthropods such as *Anthrapalaemon* and *Euproops;* also *Spirorbis*, and fish such as Acanthodians, *Rhabdoderma*, *Rhadinichthys* and *Rhizodopsis*.

The flora is represented partly by roots in the seatearths, but mainly by debris of land-plants which appears to have floated into the area of deposition and occurs in all kinds of sediments. Ferns and seed-ferns, Sphenophyllales, Equisetales and Lycopodiales are represented by numerous species. Coal itself is composed of plant-material and contains vast numbers of spores.

CLASSIFICATION[1]

The conventional division into Lower, Middle and Upper Coal Measures,

[1] Since the third edition was published the Clay Cross or Sutton Manor Marine Band has been selected by the Geological Survey as the base, and the Top or Prestwich Top Marine Band as the top, of the Middle Coal Measures.

based on lithology and local expedience, is still in use, though as at present defined the divisional boundaries do not correspond in different coalfields. The base of the Middle Coal Measures, for instance, is placed at the Arley in Lancashire and at a slightly higher horizon, the Silkstone Coal, in Yorkshire. In regard to the division between Middle and Upper Coal Measures some attempt has been made to equate this line with a palaeontological divisional line.

In dealing with the palaeontological classification there are three main schemes which now show sound indications of being complementary to one another. These are based on fossil plants, non-marine lamellibranchs and marine faunas.

On the basis of fossil plants Kidston propounded a four-fold grouping which has been modified by Crookall and finds fairly general acceptance in Britain. Dr. Emily Dix following European workers has divided the Upper Carboniferous into seven flora-zones. Her scheme has been criticised. The main difficulty in the plant-classifications is the blurring of the divisional boundaries. This has

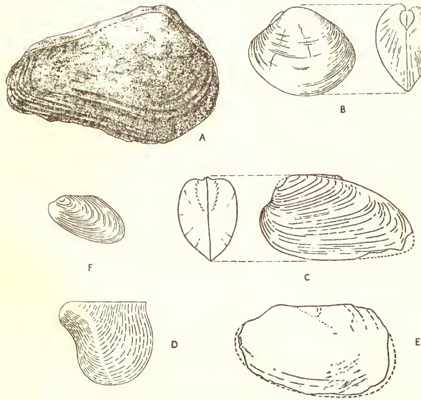


FIG. 17.—*Non-marine lamellibranchs of the Coal Measures.*
(All natural size.)

A, *Carbonicola pseudorobusta* Trueman; **B,** *Anthracosphaerium boltoni* (W. B. Wright), two views; **C,** *Anthracosia phrygiana* (W. B. Wright), two views; **D,** *Naiadites quadratus* (J. de C. Sowerby); **E,** *Anthraconaia adamsi* (Salter); **F,** *Anthraconauta phillipsii* (Williamson).

A is from J. Weir and D. Leitch, *Trans. Roy. Soc. Edin.*, vol. lviii, 1936; **E** is from A. E. Trueman, Geol. Mag., vol. lxxv, 1936. Permission to copy is acknowledged.

been met to some extent by the recommendations of the 1935 Heerlen Congress on Carboniferous stratigraphy, which adopts three marine bands to delimit stages in the Westphalian.

The zonal division of the Coal Measures on the basis of non-marine lamellibranchs, first propounded by Hind, has received great amplification and modification in the hands of Sir Arthur Trueman and his collaborators; but this scheme, like the plant-classification, suffers because of vagueness in some

Plants		Non-Marine Lamellibranch Zones	Important Marine Bands
Heerlen Congress 1935	Kidston and Crookall		
Westphalian D	Radstock Group of Radstockian	*Anthraconauta tenuis*	
	Farrington Group of Radstockian		
Westphalian C	Staffordian	*Anthraconauta philipsii*	
	—M—M—M—	—M—M—M—	Top
		Upper *Anthracosia similis* and *Anthraconaia pulchra*	
—M—M—M—		—M—M—M—	Aegir = Mansfield = Dukinfield
Westphalian B	Yorkian	Lower *A. similis* and *A. pulchra*	
		Anthraconaia	
—M—M—M—		—M—M—M—	Katharina = Clay Cross = Sutton Manor
		modiolaris	
Westphalian A	— — — — — —	*Carbonicola communis*	
	Lanarkian (= Pre-Yorkian) down to ' plant-break ' of Scotland	*Anthraconaia lenisulcata*	
—M—M—M—		—M—M—M—	*Gastrioceras subcrenatum*
Namurian			

of the zonal boundaries, and has required the selection of arbitrary boundaries such as marine horizons or thick coal seams for delimiting zones. Wright applied the scheme to the Lancashire Coalfield, and some degree of refinement was attained there by the use of a series of subzones.

Marine horizons have long been known; indeed, the recognition of the more important bands in the Yorkshire and East Midlands Coalfield by Gibson is more or less contemporary with the pioneer work of Kidston on plants and Hind on ' mussels '. Recently the importance of marine bands in this coalfield has been emphasized by Edwards and Stubblefield. Up to the present a stratigraphical study of the goniatites only demonstrates the extension of Bisat's genus-zone of *Gastrioceras* to an indefinite level between the Alton and Clay Cross marine bands, and the presence of the genus-zone of *Anthracoceras* from the Clay Cross band upwards to the Top Marine Band. But the fact that *A. vanderbeckei* is a characteristic goniatite of the Clay Cross Marine Band, and *A. hindi* of the Mansfield (though an ally has also been found in the Shafton Marine Band), and that *A. cambriense* has been found in the Top Marine Band as at the equivalent horizon in South Wales, suggests that goniatites will eventually contribute more fully to the zonal division of the Coal Measures. Further, the chief marine bands are now known to be so widespread that they may confidently be used for correlations between coalfields, and they are likely in the future to be more generally adopted as boundary-lines of major divisions (see footnote, p. 44).

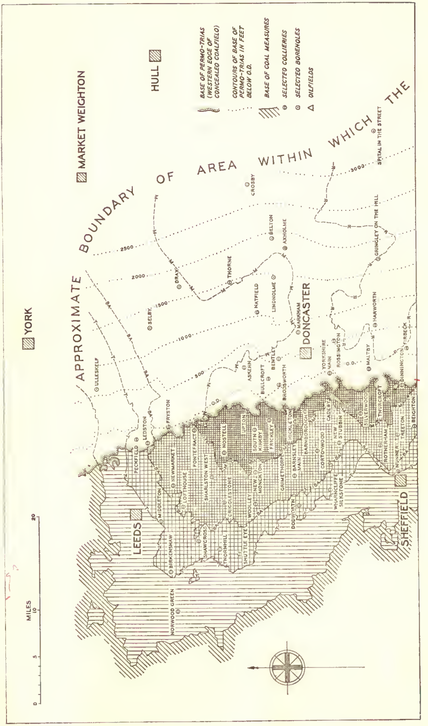
The major divisions of the various classifications are indicated in the table on the opposite page. The positions of the marine bands, however, are best seen in Fig. 16.

STRATIGRAPHY

In the following account the Coal Measures are considered in groups corresponding to the non-marine lamellibranch zones (see table above). For the most part the workable coals are confined to the *communis*, *modiolaris* and *similis-pulchra* zones, and these strata are sometimes called the Main Productive Measures (see Fig. 22).

The *lenisulcata* Zone.—Throughout the Pennine coalfields these beds, ' Lower Coal Measures ' in the Lancashire sense, maintain a surprising constancy of character. In the east almost every rhythmic unit can be followed from the northern to the southern limits of the coalfield, and several horizons persist into Lancashire and Staffordshire. Thickness is at a maximum to the west of Wigan, and gradually decreases, like that of the rest of the Coal Measures, eastwards from Lancashire towards Lincolnshire.

The only workable seams of coal occur in the lower part of the group, and with them is a remarkable swarm of marine and ' pene-marine ' horizons (Fig. 16). At the base the *G. subcrenatum* Marine Band rests on the thin Pot Clay or Six-inch Mine Coal, with its fireclay or ganister seat. The Soft Bed or Coking Coal of Yorkshire is the Belperlawn of Derbyshire and the Bassy of Lancashire. It rests on the Soft Bed Flags or Crawshaw Sandstone of the Eastern Pennines and on the Woodhead Hill Rock of Lancashire, a bed which is in many places a coarse gritstone. The Hard Bed or Alton Coal of the east is the Upper Foot or Bullion Mine of Lancashire, which is split into two seams south of Burnley where the lower, the Lower Mountain Mine, is of considerable



YORK
MARKET WEIGHTON
HULL
APPROXIMATE BOUNDARY OF AREA WITHIN WHICH THE
BASE OF PERMO-TRIAS (WESTERN EDGE OF CONCEALED COALFIELD)
CONTOURS OF BASE OF PERMO-TRIAS IN FEET BELOW O.D.
BASE OF COAL MEASURES
SELECTED COLLIERIES
SELECTED BOREHOLES
OILFIELDS
MILES
0
5
10
20
LEEDS
SHEFFIELD
DONCASTER
SELBY
ULLESKELF
DRAX
THORNE
CROSBY
BELTON
AXHOLME
LINDHOLME
HATFIELD
MARKHAM
ASKERN
BENTLEY
BULLCROFT
BRODSWORTH
GRINGLEY ON THE HILL
SPITAL IN THE STREET
HARWORTH
MALTBY
FIRBECK
DINNINGTON
BEIGHTON
ROSSINGTON
YORKSHIRE MAIN
THURCROFT
SILVERWOOD
CADEBY
NEW STUBBIN
ROTHERHAM
TREETON
NUNNERY
PECKFIELD
LEDSTON
FRYSTON
NEWMARKET
MIDDLETON
LOFTHOUSE
PONTEFRACT
NOSTELL
UPTON
SHARLSTON WEST
CRIGGLESTONE
WOOLLEY
NEW MONCKTON
SOUTH KIRKBY
FRICKLEY
GRIMETHORPE
HICKLETON
BARNSLEY MAIN
BARNBOROUGH
CORTONWOOD
DODWORTH
WHARNCLIFFE SILKSTONE
SHAWCROSS
THORNHILL
SHUTTLE EYE
BIRKENSHAW
NORWOOD GREEN
500
1000
1500
2000
2500
3000
O.D.

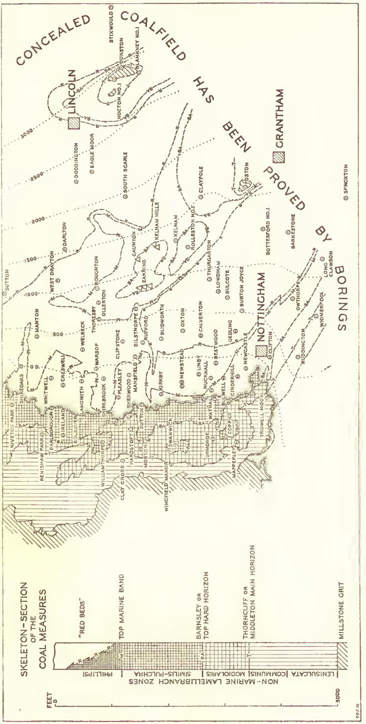


FIG. 18.—*Map of the Yorkshire and East Midlands Coalfield.*

'Outcrops' against the base of the Permo-Trias in the Concealed Coalfield are calculated.

economic importance. The marine band with *Gastrioceras listeri* which overlies this group is well known for its ' bullions '—large carbonate nodules which contain shapely and beautifully ornamented goniatites. Bullions of a different type occur locally in the coal and contain plant-debris with the various delicate tissues well preserved.

The most notable of several refractory seatearths in these measures is the ganister below the Hard Bed Coal, and the whole group of beds is, in fact, sometimes called the ' Ganister Coal Series '.

A number of thin coals with fireclay seats lie above the *G. listeri* horizon (Fig. 16). Locally there are also prominent beds of sandstone such as the Helpet Edge Rock of Lancashire and the Loxley Edge and Wharncliffe Rocks of Yorkshire.

In the upper part of the *lenisulcata* Zone is a strong development of flaggy sandstones throughout the Pennines, with various local names, e.g. Elland Flags in West Yorkshire, Wingfield Flags in Derbyshire, Old Lawrence or Hambleton Scout Rock and Upholland Flags in Lancashire.

The Coal Measures of the three small outliers near Buxton on the South Pennine moorlands belong to this zone and are similar to the measures lying west and east of them. ' Lower Coal Measures ' are also represented in the lowest beds of the Ingleton Coalfield (these, possibly with an attenuated representative of the ' Main Productive Measures ', are overlain by red mudstones with beds of limestone, coaly shale and sandstone of uncertain age).

Nine marine and ' near-marine ' bands are known in the *lenisulcata* Zone, both in Lancashire and in Derbyshire and Yorkshire, and contain *Lingula mytilloides* in all cases; six of these bands contain elements of a fuller fauna which includes the goniatites *Gastrioceras subcrenatum* and *G. listeri*, and *Dunbarella* and other lamellibranchs. Non-marine lamellibranch bands are common in this zone, and contain *Carbonicola* of the *C. fallax–C. protea* groups, and a number of other shells.

Plant-impressions occur at many horizons, the most distinctive forms being *Neuropteris schlehani* and *Sphenopteris hoeninghausi*, species characteristic of the Lanarkian of Kidston and Crookall.

The *communis* Zone.—In Lancashire this division consists mainly of mudstones with unimportant sandstones, but with several coal seams, the most valuable being the Arley or Royley Mine near the base. Other important seams include the Rushy Park, the Yard, and the Ravine which is also described as the Plodder. In the higher part of this group the Black Mine is an important coal in the western part of the coalfield, and in the central area the Cannel Mine occurs at about the same horizon. This coal is frequently split by a shale parting into two separate seams, the lower portion forming the King Mine of the Tyldesley district.

In Yorkshire the corresponding measures contain variable beds of sandstone and several coals, of which the Better, Black and Beeston are important in the north and the Silkstone in the south. The valuable seams of Derbyshire and Nottinghamshire include the Kilburn near the base of the zone, the Blackshale (which unites with the overlying Yard to form the Silkstone of South Yorkshire), and the Tupton or Lowmain. An important index-horizon, the Low ' *Estheria* ' band, lies close below the Silkstone Coal in Yorkshire, and has also been found in Derbyshire and Nottinghamshire.

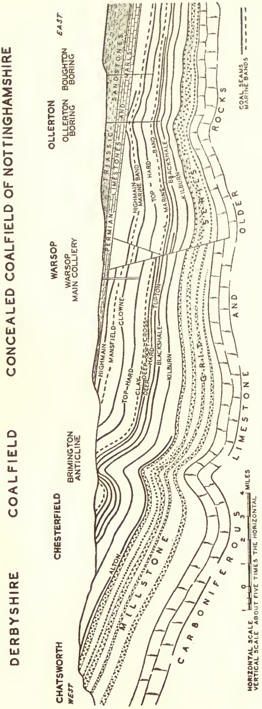


FIG. 19.—*Section across the Yorkshire and East Midlands Coalfield.*

There are numerous bands with non-marine lamellibranchs in this zone, and in these the genus *Carbonicola* abounds, common species being *C. communis*, *C. martini*, *C. pseudorobusta* and *C. rhomboidalis*. There are also *Naiadites* and small *Anthraconauta*.

Plant impressions are more abundant than in the underlying measures. The Lanarkian species *Neuropteris schlehani* and *Sphenopteris hoeninghausi* die out in this zone, but other forms such as *Alethopteris lonchitica* and *Neuropteris heterophylla* range upwards into the Yorkian.

The *modiolaris* Zone.—The measures in this group are more variable than those below. In the Lancashire Coalfield one of the best known and more important coals is the Trencherbone Mine of the Bolton and Tyldesley districts which is also known as the Wigan Six Foot in the neighbourhood of Wigan. This coal occurs at the base of the group and is represented in the Oldham district by a thick seam known as the Oldham Great. In the vicinity of Wigan two important coals known as the Wigan Four Foot and Wigan Five Foot occur in the lower part of the *modiolaris* Zone. These have also been worked in the St. Helens district, where they are referred to as the Main and High Ravenhead mines respectively. A thin seam above the latter, the Park, is noteworthy because it is overlain by the Sutton Manor Marine Band. This is the mid-*modiolaris* Marine Band of most British coalfields. The Pemberton Four Foot and Pemberton Five Foot coals occur in the topmost measures of the *modiolaris* Zone and have been extensively mined around Wigan. In the vicinity of St. Helens they are also of high economic value and are described as the Higher and Lower Florida mines respectively. Other seams include the Black and White mines of the Tyldesley district and the Stubbs Mine which has been worked in the eastern part of the coalfield. Many of the coals, particularly in the central part of the coalfield, are liable to what are termed ' washouts ' or removal by erosion of the coal seam over certain areas, the place of the wanting seam being taken by part of the overlying sandstone. The Trencherbone is in this way often replaced by the basal part of the overlying Trencherbone Rock, which is usually of a conglomeratic nature in its lower part. Four main belts of sandstone occur in the measures referred to this group, and each shows extremely rapid variations in texture and thickness. Frequently the base of these sandstones is conglomeratic and consists of materials derived from the erosion of the underlying beds.

In Yorkshire and the East Midlands the corresponding measures are of similar lithology, and include several valuable seams of coal. The Middleton Main or Thorncliff at the base and the somewhat higher Parkgate are notable Yorkshire seams; the Deep Hard and Deep Soft are seen at their best in Derbyshire, and the Haigh Moor in West Yorkshire. Seams in the Waterloo group are good locally, and so is the Dunsil, which in some easterly areas is united with the Barnsley (p. 54). Several variable beds of sandstone occur in the *modiolaris* Zone and, like those in Lancashire, are sometimes found to encroach on underlying beds in ' washouts '.

The only known marine horizon in this zone is the Clay Cross Marine Band. It is conspicuous throughout the East Pennine coalfield, and is equated with the Sutton Manor Marine Band of Lancashire. Its fauna (from the East Midlands) includes cephalopods—especially the goniatite *Anthracoceras vanderbeckei*—foraminifera, lamellibranchs such as *Dunbarella*, *Edmondia* and *Myalina*, small gastropods, conodonts and fish. *Lingula mytilloides* is common, and in

Yorkshire is often the only marine fossil found. In Derbyshire and Nottinghamshire a feature of the band is its upward passage by interdigitation into non-marine shelly beds.

Throughout the Pennine coalfields non-marine lamellibranchs abound at several horizons in this zone. The genus *Carbonicola* dies out, but the genus *Anthracosia* appears suddenly and in great force, with such forms as *A. regularis*,

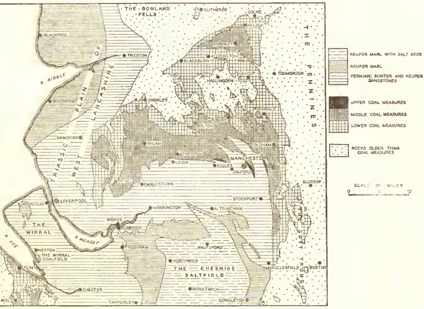


FIG. 20.—*Map of the Lancashire and Cheshire Coalfield and the Saltfield of north Cheshire.*

A. aquilina (a long-ranging form) and *A. retrotracta*. *Anthracosphaerium* is abundant, with *A. affine* and *A. exiguum*; and among the species of *Anthraconaia* there is *A. williamsoni*.

Plants are found in greater variety than in the measures below. Common species are *Alethopteris lonchitica*, *A. decurrens*, *Neuropteris heterophylla* and *N. tenuifolia*.

The Lower ***similis-pulchra*** **Zone.**—In Lancashire the Ince group of seams lies in the lower part of this zone. In the Wigan area the seams in upward succession are known as the Ince Furnace, Ince Seven Foot, Ince Four Foot, and Ince Deep Yard. Farther east these names give place to Rams, Brassey, Crumbouke and Bin, whilst in the area east of Manchester the Ince group is represented by the Bottom and Top Furnace, Roger and Ashton Great, and possibly the Major. A group of measures lying between the Ince group of seams and the Dukinfield Marine Band thickens from 200 ft. in the south-west to 700 ft. in the east. It contains seams of only local importance, of which the Park in the Wigan area and its correlative the Ashclough in the East Manchester field may be mentioned.

East of the Pennines the basal member of the zone is the famous Barnsley Coal of Yorkshire, known in Nottinghamshire and Derbyshire as the Top Hard. This seam has been proved to be workable over more than 700 square miles; indeed, more than 200 square miles of it are already worked out. The 'Hards', usually present between Top and Bottom 'Softs', and in places

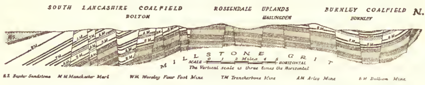


FIG. 21.—*Section across the Lancashire and Cheshire Coalfield.*

forming more than half the seam, are good steam-coal, and the whole seam is of great value and has a good roof (except where 'washouts' occur). Other important seams include the Stanley Main in the north and the High Hazles in the south, the Wathwood or Mainbright and the Newhill or Clown. Of the occasional beds of sandstone the Woolley Edge Rock is in one area of Yorkshire a coarse gritstone, and the higher Oaks Rock is also notable.

Marine bands, mainly with a limited fauna of *Lingula* and *Orbiculoidea*, occur at four levels in the upper part of the zone (Fig. 16).

Non-marine shells are common, though not so abundant as in the underlying zone. *Anthracosia* is represented by *A. simulans* [formerly *A. similis*] and by a number of commoner species including the 'short-range' forms *A. fulva* and *A. atra*. *Anthracosphaerium* is occasionally found, and there are several forms of *Anthraconaia* including *A. pulchella* Broadhurst. *Naiadites* includes some forms with a curved posterior wing, and shells with a deceptive resemblance to *Anthraconauta phillipsii*.

Plants are numerous at many horizons, characteristic forms being *Corynepteris*, *Alethopteris lonchitica*, *Neuropteris obliqua* and *Sphenopteris laurenti*.

The Upper *similis-pulchra* Zone.—When these measures were laid down the formation of coal was on the wane. In the Lancashire Coalfield only two seams attain economic importance, the Parker Mine and the Worsley Four-Foot. In Yorkshire and the East Midlands a number of second-quality coals are found: the three Sharlston coals (Yard, Low and Top) of Yorkshire, of which the Top is the Highmain of Nottinghamshire, there the uppermost seam worked; and the Shafton, which is only recognizable in the north. Sandstones are of some importance in Yorkshire, where the Mexborough Rock is developed over a wide area and is conspicuous by its reddish brown colour.

In Lancashire the pronounced west-to-east thickening of the measures, apparent in the Lower, is also present in the Upper *similis-pulchra* Zone. Whereas the zone near Cronton in the south-west is about 400 ft. thick, it is 850 ft. thick at Manchester. East of the Pennines the same measures thin eastwards and south-eastwards from 600 ft. near Barnsley to about 300 ft. near East Retford.

Throughout the Pennine coalfields the base of the zone is the Mansfield or Dukinfield Marine Band. In Yorkshire and the East Midlands the Mansfield

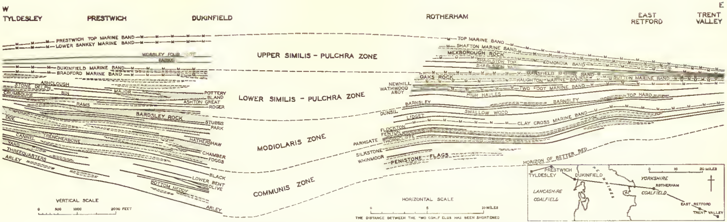


FIG. 22.—*Diagrammatic section showing the main productive measures in the coalfields west and east of the Pennines.*

Correlation of corresponding groups of measures in the Lancashire Coalfield on the west and the Yorkshire and East Midlands Coalfield on the east has been established by means of the non-marine lamellibranchs and the marine bands. The Dukinfield Marine Band is the Mansfield and the underlying Bradford Marine Band is probably the Haughton: the Prestwich Top Marine Band is the Top Marine Band and the underlying Lower Sankey is the Shafton. The diagram illustrates the regional variation in thickness of the measures and shows that sedimentation, and therefore contemporary subsidence, was greatest on the site of the Pennines.

band is well known owing to its value as a 'marker' in coalfield-exploration. It consists of dark shelly mudstones up to 30 ft. thick, with a thin but conspicuous layer of hard ankerite-siltstone—the 'cank'—close above their base. The abundant fauna includes foraminifera, sponge-spicules, crinoid-stem columnals, brachiopods including in the 'cank' some calcareous-shelled forms like *Chonetes*, many specics of lamellibranchs, gastropods, cephalopods including especially the goniatite *Anthracoceras hindi*, conodonts and fish. The Dukinfield band of Lancashire contains a comparable fauna.

Of the higher index-bands in this zone, the *Edmondia* Band is notable for its fauna of marine lamellibranchs such as *Edmondia* and *Myalina* and for abundant foraminifera, *Lingula* being rare. The Main '*Estheria*' Band, though not usually marine, is a widespread 'marker' in Nottinghamshire, and in one locality the rhythmic unit has yielded *Lingula*. The Shafton Marine Band contains in Nottinghamshire a meagre fauna of horny brachiopods and foraminifera, accompanied by the distinctive lamellibranch Cf. *Anthraconaia pruvosti* (Weir and Leitch *non* Chernyshev). In Yorkshire this fauna is reinforced by *Myalina*, *Edmondia*, *Dunbarella* and other lamellibranchs, and by gastropods. *Euestheria* is found both in the rhythmic unit and in several units above and below it. In Lancashire forms related to *A. pruvosti* are not confined to one horizon but have a range within the zone. Nevertheless the form termed Cf. *A. pruvosti* is abundant in the Lower Sankey Marine Band which also yields *Myalina compressa* and *Lingula*. This marine band is regarded as the equivalent of the Shafton Marine Band.

The Prestwich Top Marine Band is taken as the divisional line between Upper *similis-pulchra* and *phillipsii* zones. This band equates with the Upper Sankey Marine Band of south-west Lancashire, and with the Top Marine Band east of the Pennines. In Yorkshire and the East Midlands the Top Marine Band is a prominent horizon throughout all but the remotely eastern parts of the coalfield. It has yielded a fauna of foraminifera, horny brachiopods, lamellibranchs such as *Dunbarella*, *Myalina* and *Nuculana*, gastropods such as *Euphemites*, and cephalopods including *Anthracoceras cambriense*.

In this zone non-marine lamellibranchs are much reduced in both genera and species. *Anthracosia* and *Anthracosphaerium* have disappeared; but the genus *Anthraconaia* persists through the zone, with the distinctive shells *A. adamsi* and *A. warei*; and various species of *Naiadites* are found, some of which resemble *Anthraconauta phillipsii*.

The *phillipsii-tenuis* measures.—In Lancashire this group of measures can be readily divided into three divisions—a Lower Group, a Limestone Group and an Upper Group. The upper two groups fall within the *tenuis* Zone and the lower group probably lies within the *phillipsii* Zone.

In the south-west the Lower Group is 400–500 ft. thick and consists mainly of sandstones and sandy shales yielding an impoverished fauna. In accordance with the general rule the measures thicken eastwards, and at Manchester the Lower Group is 1,300 ft. thick and includes the following coal seams: Two Foot, Yard, Bradford Four Foot, Three Quarters, Charlotte and Openshaw.

The Limestone Group consists of freshwater-limestones and occasional dolomites (not infrequently so fine-grained and porcellanous as to be termed calcite-mudstones and dolomite-mudstones) interbedded with calcareous mudstones and including two coal-horizons. The fauna includes *Anthraconauta tenuis*, *A. phillipsii* and intermediate forms between these two species, *A. calcifera* and *Anthraconaia* aff. *pruvosti* (Chernyshev), *Leaia, Spirorbis* and abundant ostracods. These beds expand from 200 ft. in the south-west to 300 ft. at Manchester.

The Upper Group consists of sandstones and mudstones with occasional thin limestones and several thin coal seams. It is known only in the south-west, where it is 400 to 500 ft. thick and yields a fauna similar to that of the Limestone Group with in addition *Anthraconaia prolifera* (Melville *non* Waterlot) and also abundant *Euestheria* at several horizons, and occasional *Estheriella*.

In Lancashire reddened beds (red, purple, green and variegated mudstones, red to brown sandstones and pink limestones) are found immediately beneath the base of the Permo-Triassic rocks. Reddening affects rocks varying in age from the P zone of the Carboniferous Limestone Series to the *tenuis* Zone of the Coal Measures. The depth of reddening below the Permo-Triassic rocks varies, but usually is of the order of 1,000 ft.

In Yorkshire and the East Midlands similar reddened beds are general beneath the uncomfortable base of the Permo-Trias and are recognized as due to the same cause as in Lancashire (i.e. the oxidation of ferrous iron on and below the pre-Permian land-surface); but they seldom penetrate the Coal Measures to more than a few feet and rarely to as much as 100 ft. They are not to be confused with the ' Red Beds ' or ' Red Measures '—a sedimentary series which, as described below, overlies, and passes laterally northwards into, the grey Coal Measures of Nottinghamshire.

East of the Pennines the Coal Measures of the *phillipsii* (and ? *tenuis*) Zone exhibit two markedly different lithological facies. The lower consists of grey measures of normal appearance but with a restricted fauna (see below), coals which are usually thin and inconstant, and prominent beds of sandstone. The ' Red Beds '—the ' Upper Coal Measures ' of some authors—are soft marly-looking mudstones coloured reddish brown, and also green, purple and khaki, with ill-graded sandstones (' Espley Rocks ') and almost without fossils or coals. Near Nottingham the grey measures above the Top Marine Band are only 170 ft. thick, and are then succeeded by a great thickness of Red Beds: but in a northerly direction these Red Beds pass laterally into grey measures, so that in South Yorkshire there are at least 1,000 ft. of grey measures above the Top Marine Band. Here they contain conspicuous beds of coarse sandstone such as the Ackworth, Pontefract and Wickersley Rocks, and several coals which are too thin to be workable. The fauna of these grey measures resembles that of the equivalent beds of Lancashire, with *Euestheria, Estheriella, Anthraconauta phillipsii* at many horizons, and in the higher beds *A. wrighti* and *A.* cf. *tenuis*.

The Red Beds have been proved in boreholes and sinkings to be over 600 ft. thick, and to extend widely under the Permo-Trias in Nottinghamshire and Lincolnshire, though they do not crop out in the exposed parts of the coalfield. Their lower beds resemble the Etruria Marls of Staffordshire and the West Midlands and are believed to have been deposited under similar conditions though not necessarily at the same time; and in parts of Nottinghamshire there is intercalated with them up to 100 ft. of grey measures which bear some resemblance to the Newcastle under Lyme Beds of Staffordshire. In Lincolnshire a higher group of Red Beds is proved in a few boreholes. They are similarly coloured 'marls' with very coarse sandstones and conglomerates, resting unconformably on various horizons of the underlying Coal Measures.

Plants are less abundant in the *phillipsii-tenuis* measures than in lower zones. Some distinctive species are *Alethopteris serli*, *Asterotheca miltoni*, *Linopteris muensteri* and *Neuropteris rarinervis*.

ASSOCIATED IGNEOUS ROCKS

Olivine-dolerites and analcime-dolerites have been encountered in many boreholes south-east of a line through Nottingham and Lincoln. They are most abundant in the lower part of the Coal Measures, and they appear to be mainly intrusive sills. They are dark greenish-grey rocks, often amygdaloidal, and their constituent minerals are generally much decomposed. Bulky intrusions were encountered near the base of the Coal Measures in the oilfields at Caunton and Kelham Hills, and some of them were highly altered and carbonated. In the same area a higher bed of dolerite, close to the horizon of the Clay Cross Marine Band, is believed to be extrusive.

A

B

D

C

E

F

FOSSIL PLANTS TYPICAL OF THE COAL MEASURES

(A-D, F, half natural size; E, natural size)

Main productive measures (up to base of *phillipsii* Zone).—**A,** *Neuropteris heterophylla* Brongniart; **B,** *Mariopteris muricata* (Schlotheim); **C,** *Alethopteris lonchitica* (Schlotheim). Higher measures.—**D,** *Sphenophyllum emarginatum* Brongniart; **E,** *Linopteris münsteri* Eichwald; **F,** *Alethopteris serli* Brongniart.

(For description, *see* p. v) (*Photo: H. G. Haywood*)

A.—STALACTITES AND STALAGMITES, GINGLING HOLE, FOUNTAINS FELL

(For description, *see* p. v)

B.—GRIMBALDS CRAG, KNARESBOROUGH

VII. PERMO-TRIASSIC ROCKS

THE CLOSE of the Carboniferous period was marked, in this area, by the culmination of the Hercynian earth-movements. Although the rocks of northern England escaped the intense shearing and distortion which overtook those now seen in South Wales and the Bristol area, yet they were uplifted, flexed and faulted, and subjected to erosion on a vast scale before they were overspread by the Permian sea. Nowhere is the magnitude of this pre-Permian erosion more impressively displayed than along the eastern slopes of the Pennines. Here the Permian rocks lie at Doncaster on some 5,000 ft. of Coal Measures; at Bramham, 24 miles to the north, on the base of the Coal Measures; and at Richmond, a further 40 miles north, on horizons within the 'Yoredale Beds'. However generously the northward attenuation of the Carboniferous rocks be allowed for, it is clear that some thousands of feet of them were denuded during the interval. Similarly in Lancashire, near St. Helens, the basal Permo-Triassic sandstone rests on beds high in the *tenuis* Zone, and to the north-west at Formby on the Lower *Eumorphoceras* Stage of the Millstone Grit, indicating denudation of the order of 10,000 feet in a distance of 20 miles.

Whereas many of the Hercynian folds were completely worn down during this interval (see for instance Fig. 19), others stood up as low barriers dividing one basin of Permian deposition from another. The Pennine uplift appears to belong to this category: for on the west of it the common types of Permian rocks are sandstones and marls, with very little limestone; and on the east they are magnesian limestones with subordinate beds of marl and sandstone, laid down in what is believed to have been an extension of the Zechstein Sea of Germany.

The Permian rocks—to judge by the prevalent red colour of their marls and sandstones, the abundance in them of wind-worn grains of sand, and the common association of dolomite with anhydrite and gypsum, salt and other evaporites—appear to have accumulated under dominantly, or at least intermittently, arid conditions, in basins wholly or in part cut off from the open sea. In these basins the salt-content of the water became concentrated at times to the point of chemical precipitation; and at its best the fauna of the magnesian limestones (almost no fossils are known from the red marls and sands) is a meagre one compared with that in the underlying rocks, as if its environment were barely tolerable.

The Triassic sediments appear to have been associated with similar climatic conditions, but they spread far beyond the limits of the Permian and were deposited more uniformly on both sides of the Pennines. They are mainly 'marls' (quartzose mudstones), which though deposited in shallow water were perhaps originally wind-borne, sands, and pebble beds which suggest the work of torrential floods. The whole is predominantly red. Evaporites are again important in the upper part of the formation, but no marine sediment reached the area until the mud-laden Rhaetic sea ushered in the Jurassic period.

The lithological divisions of the Permo-Trias are shown in the table below. The age of these various divisions is not precisely the same throughout the area: and in particular the Permian of Nottinghamshire passes laterally southwards into the lower part of the Bunter.

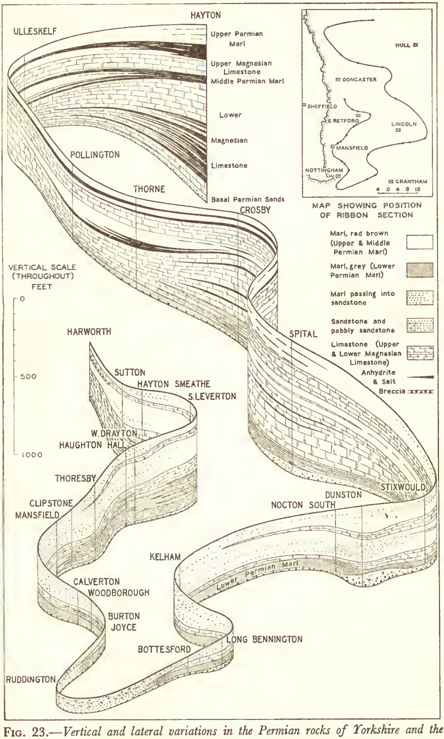


FIG. 23.—*Vertical and lateral variations in the Permian rocks of Yorkshire and the East Midlands, illustrated by a ribbon-diagram.*

(In the inset map the line with dots on one side indicates the outcrop of the base of the Permian).

Lithological Divisions of the Permo-Trias

LANCASHIRE	YORKSHIRE AND EAST MIDLANDS
TRIAS	TRIAS
Keuper Marl	Keuper Marl
Waterstones	Waterstones
Keuper Sandstone	
Bunter Sandstone, comprising:	Bunter Sandstone, comprising:
Upper Mottled Sandstone	
Pebble Beds	Pebble Beds
Lower Mottled Sandstone	Lower Mottled Sandstone
PERMIAN	PERMIAN
Manchester Marls	Upper Permian Marl
	Upper Magnesian Limestone
Collyhurst Sandstone	Middle Permian Marl
	Lower Magnesian Limestone
	Lower Permian Marl
	Basal Sands and Breccia

PERMIAN: EAST OF THE PENNINES

The Permian rocks crop out in a continuous strip about 5 miles wide between Darlington and Nottingham, their basal beds rising above the Carboniferous rocks in a distinct escarpment. From Worksop southwards to Nottingham they gradually pass laterally, as was first demonstrated by R. L. Sherlock, into the lowest beds of the Bunter Sandstone. They dip steadily eastwards under the Trias, increasing in thickness towards the north-east. The chief variations in their thickness and lithology are shown in Fig. 23.

Basal Sands and Breccia.—Along the outcrop between Knaresborough and Worksop there lies an inconstant bed, seldom as much as 20 ft. thick, of honey-yellow sands with wind-frosted grains, underlain in places by a thin conglomerate; and similar sands, blue-grey at depth, are present under more easterly parts of Yorkshire. South of Worksop the sands are generally replaced by the 'Basal Breccia', a conglomerate with angular and rounded pieces of Carboniferous and older rocks, and with interstitial grains of sand of the Yorkshire type. South of Nottingham this is a coarse breccia with much material of Charnian type, overlain directly by Bunter Sandstone and, in places, by Keuper Marl. The thickness of the Basal Breccia shows wide variation, but under much of Nottinghamshire it is only a few inches.

Lower Permian Marl.—Throughout Nottinghamshire and much of the concealed coalfield in Yorkshire a few feet of grey limy mudstones underlie the Lower Magnesian Limestone. These have been called Marl Slates by some authors (they bear little resemblance to the beds of that name in Durham) and 'Grey Beds' by Sherlock. They generally contain an abundant marine fauna, including bryozoa such as *Fenestella retiformis*, brachiopods such as *Lingula credneri* and *Productus* (*Horridonia*) *horridus*, lamellibranchs such as *Bakevellia antiqua* and *Schizodus*, and fish. Around Nottingham they exhibit a near-shore facies of flaggy siltstones with much plant-debris, and they die out south of the city.

Lower Magnesian Limestone.—Yellow dolomitic limestone occupies most of the outcrop, and includes oolites, 'minutely-cellular' rocks from which the ooliths have been dissolved, granular aggregates of dolomite crystals—a widespread rock-type, shelly limestones and reef-limestones. The reefs, which occur along the outcrop between Leeds and Worksop, are squat masses of hard unbedded limestone, shelly in places, distributed irregularly among the normally bedded limestones. In Nottinghamshire the Lower Magnesian Limestone is locally sandy; it also contains much grey fossiliferous marl like the Lower Permian Marl (Fig. 23), and its junction with that division is not in all places readily found.

In the north-east the Lower Magnesian Limestone increases to a great thickness, and much of its lower part passes into anhydrite. In the south it dies out in the neighbourhood of Nottingham.

Fossils are often found in abundance in the lower part of the group, especially in the grey marly beds mentioned above, and in parts of the reefs. They include several species of foraminifera; bryozoa, brachiopods and lamellibranchs (Plate X); and occasional crinoids, nautiloids, ostracods and plants.

Middle Permian Marl.—In Yorkshire the narrow outcrop reveals red marl, with grey silty bands and with gypsum. Evaporites increase in thickness north-eastwards, and in boreholes near Market Weighton the group consists almost entirely of rock-salt and anhydrite. Near Worksop a band of breccia with pieces of sandstone, quartzite, chert and igneous rocks lies near the top of the marls, notably at Harworth Colliery; and hereabouts the upper part of the group begins to pass southwards into sands of Bunter type, though a basal bed of red marl persists to the neighbourhood of Nottingham. The only signs of former life that have been found in the Middle Permian Marl are borings, tracks and casts of some creature, perhaps a worm.

Upper Magnesian Limestone.—Platy grey limestones overlie the Middle Permian Marl in Yorkshire, where they reach about 100 ft. in thickness. They exhibit a gradual southward attenuation and die out between Worksop and Mansfield though they persist eastwards into the Lincoln area. They are mainly calcite-mudstones. Much of the group is free from magnesia and is an important source of agricultural lime. They contain a fauna comprising only a few of the species found in the Lower Magnesian Limestone, and those often dwarfed as by an unfavourable environment.

Upper Permian Marl.—Similar in lithology to the Middle Permian Marl, these beds contain important deposits of gypsum and, at depth in the north-east, anhydrite and rock-salt. In Nottinghamshire they gradually pass southwards into sandstones and, with the disappearance of the Upper Magnesian Limestone at their base, unite with the main part of the Middle Permian Marl to become the lower beds of the Bunter Sandstone (Fig. 23). They are unfossiliferous.

PERMIAN: WEST OF THE PENNINES

In the extreme north of our region and continuous with the outcrop in Edenside there is an area of Permian between Brough under Stainmore and Kirkby Stephen. There is an isolated exposure at Ingleton doubtfully referred to the Permian. Farther south there is an outcrop on the northern margin of the Lancashire Coalfield which, however, is greatly obscured by Glacial Drift. The principal outcrop flanks the northern and north-eastern margins of the Cheshire Plain, extending from St. Helens eastward to Manchester and then southwards to beyond Stockport.

West of the Pennines the Permian consists of a sandstone group overlain by a marl group.

The Sandstone Group.—This normally commences with a conglomerate or breccia and is succeeded by coarse, red, rounded-grained sandstones (which locally develop thin breccias) known in Edenside as the Penrith Sandstone and in Lancashire as the Collyhurst Sandstone.

The maximum thickness in Edenside, including the breccias which are locally known as Brockrams, is 1,500 ft., but this decreases rapidly southwards towards Kirkby Stephen. A thickness of 2,360 ft. is recorded from a deep bore at Formby. This also is an exceptional thickness for the area to the north-west of the Lancashire Coalfield.

On the northern margin of the Cheshire Plain where the sandstone is best known its thickness varies from nil to 800 ft. In this area changes of thickness on opposite sides of faults have been interpreted as indicating movement along the fault-planes in Permian times. Movement along major faults during Permian times has also been deduced from the composition of the pebbles in the breccias. The basal conglomerate or breccia contains pebbles that have been derived exclusively from Carboniferous rocks, whilst breccias at higher horizons contain, in addition, pebbles of pre-Carboniferous rocks. The pre-Carboniferous pebbles are considered to afford evidence of elevation on the upthrow side of the nearby major fracture and consequent erosion down to pre-Carboniferous beds. On the basis of pebble evidence the Dent, Craven and Red Rock faults have been claimed to have moved during Permian times. The argument ignores the possibility that the pebbles of pre-Carboniferous rocks may have been derived from Carboniferous conglomerates.

The Marl Group.—In the part of Edenside which falls within our region the beds consist of red and grey marls with obscure plant-remains and much fibrous gypsum, and are known as the Hilton Plant Beds. In the River Belah they are capped by about 10 ft. of magnesian limestone.

In Lancashire, notwithstanding a red coloration, the marls, here known as the Manchester Marls, display a marine aspect, particularly near their base. They have yielded such characteristic Permian fossils as *Pleurophorus costatus*, *Schizodus schlotheimi*, *Bakevellia antiqua* and *Liebea squamosa*. The fossils occur both in the marls and in thin bands of limestone interbedded with the marls.

The Manchester Marls at and near the surface vary in thickness from less than 50 ft. to 150 ft. At depth, however, in the Formby area they have been proved to be 400 ft. and at Scarisbrick 700 ft. thick. These thick measures, however, present a sandy facies, and possibly include the equivalents of both the underlying Collyhurst Sandstone and the overlying Lower Mottled Sandstone.

TRIASSIC

Not only were the Triassic rocks deposited over a wider area, but they also show greater uniformity than the Permian, and most of the divisions are recognizable throughout the areas adjacent to the Pennines.

Bunter

The Bunter formation is most typically and fully developed in Cheshire and south-west Lancashire, where it attains a thickness of nearly 3,000 ft. and consists largely of soft red and mottled sandstone. A group of more compact and coarse-grained sandstones, with rounded pebbles scattered throughout, occurs in the midst of this thick series and is described as the Bunter Pebble Beds. A threefold division of the Bunter has therefore been made in this area, the sandstones above and below the Pebble Beds being referred to as Upper and Lower Mottled Sandstones respectively. The Pebble Beds are not everywhere present and it is then impossible to distinguish the upper and lower divisions from one another. The Bunter sandstones were evidently laid down in shallow water, for they are strongly and irregularly current-bedded, a feature indicating powerful and constantly-changing currents. They are heavily stained with ferric oxide and are almost without fossils. Their extensive areas of outcrop and their permeable nature make them a valuable source of underground water-supply.

Lower Mottled Sandstone.—This is a fine-grained soft sandstone, usually bright red in colour and occasionally mottled with yellow and white patches. Some loosely-compacted layers contain wind-worn sand grains, including the well-rounded ' millet-seed ' sands. The Lower Mottled Sandstone is well developed in the Wirral, in Cheshire and South Lancashire, and in Nottinghamshire where it passes northwards into Permian beds.

Bunter Pebble Beds.—Of coarser grain than the beds above and below them, and generally of a more yellow or buff colour, these sandstones are distinguished by the presence of well-worn pebbles and cobbles up to about 7 in. long. In some southern districts the pebbles form gravelly aggregates which justify the name given to the group; more frequently they are found scattered thinly through the sandstone or along bedding-planes. Their most abundant varieties are grey and liver-coloured quartzites, and white, yellow and pink vein-quartz; but there are occasional pebbles of granite, felsite, mica-schist, chert and sandstone, and some contain fossils of Carboniferous and earlier ages. Towards the north the sandstone becomes thicker, but the pebbles dwindle in size and in abundance, as if derived from some southern region.

The Pebble Beds are well developed in Cheshire and South Lancashire where they often yield a serviceable building stone; also in Nottinghamshire where they form the attractive scenery of Sherwood Forest and occasionally stand out in prominent crags. Towards the north on both sides of the Pennines, as mentioned above, pebbles gradually disappear; and at Garstang in Lancashire, and north of Doncaster in Yorkshire, there is 1,000 ft. of Bunter Sandstone with few or no pebbles, which is not readily subdivided.

Upper Mottled Sandstone.—Absent from Nottinghamshire, and not recognizable as a separate subdivision to the north of Doncaster, the Upper Mottled Sandstone is well developed in the Wirral, in Cheshire and in South Lancashire. Here it is a fine-grained rock and varies in coherence from a moderately firm stone, used locally for building purposes, to a soft sand which may be readily dug and is used as moulding and building sand. In general character it is indistinguishable from the Lower Mottled Sandstone.

Keuper

In most areas the basal Keuper is sharply differentiated from the underlying Bunter, being a hard, coarse-grained sandstone or, as in the Nottingham area, a conglomerate. It is even more widely transgressive than the Bunter, overlapping that formation onto Carboniferous and older rocks to the south of

Nottingham. Unlike the lower beds of the Permo-Trias it is of substantial thickness throughout the area, being 700 to 1,000 ft. on the east of the Pennines and over 4,000 ft. in Cheshire.

Where the Keuper is fully developed a threefold division is readily made, into Keuper Sandstone at the bottom, Waterstones, and Keuper Marl at the top. All three groups merge into one another, becoming progressively finer in grain until the clay of the Keuper Marl, with its evaporite beds, overspreads the other Triassic rocks.

Keuper Sandstone.—In South Lancashire and Cheshire the sandstone is well developed and has an average thickness of about 400 ft. In several places, notably around Runcorn and Alderley Edge in north-east Cheshire, its basal beds are coarse-grained and conglomeratic. Normally it is a grey sandstone with occasional layers of quartz pebbles and rolled pellets of marl. Over a large area in northern and central Cheshire, however, the highest beds are mottled red and yellow false-bedded sandstones, indistinguishable in appearance from the underlying Upper Mottled Sandstone. They form marked features in the Frodsham, Helsby and Delamere districts where they have been called Frodsham Beds.

The Keuper Sandstone has been extensively quarried for building stone in the vicinity of Storeton, Runcorn and Lymm. About 120 ft. above its base in these quarries is a well-marked 'footprint' bed, with casts of footprints of reptiles, including the genera *Cheirotherium* and *Rhynchosaurus*; these are found on the under side of a bed of sandstone overlying marly clay. This bed also yields abundant impressions of ripple-marks, suncracks and obscure plant remains.

The Keuper Sandstone maintains its normal character and thickness in the Liverpool district though it thickens considerably when traced northwards, and deep borings in the vicinity of Formby reveal a thickness of upwards of 1,000 ft.

In parts of South Derbyshire the basal breccia of the Permo-Trias is overlain by sandstone which is considered by some geologists to be of this age, and by others to be part of the Waterstones. Near Nottingham only a thin bed of conglomerate lies between the Bunter and the Waterstones.

Waterstones.—These are an alternating series of thin-bedded marly brown sandstones and soft sandy marls and variegated shales. The sandstones are often ripple-marked and are apt to show, on their nether surfaces, pseudomorphs after rock-salt.

The Waterstones are well developed in Cheshire and South Lancashire where they pass up imperceptibly into the Keuper Marl. They are thin in South Derbyshire but thicken eastwards to about 100 ft. near Nottingham and to still more at depth near Newark. In these areas their lower part consists of greenish-grey clays and shales (the 'Green Beds'), in good repute for brickmaking and pottery.

Among rare fossils are the small crustacean *Euestheria minuta*, fish, plant-remains and footprints referred to Reptilia and Amphibia.

Keuper Marl.—Remarkably uniform lithology is displayed by this, the most widespread group of the Permo-Triassic rocks. In all areas the 'marl' is a silty red clay with thin bands and patches of greenish hue; but it includes at many horizons thin bands, or groups of bands, of fine-grained sandstone which is often dolomitic. These, the so-called 'skerries', weather out into distinct features and give the Keuper Marl country a relief which is in places unexpectedly strong.

In Cheshire the Keuper Marl attains its fullest development in Britain. Deep borings in the vicinity of Northwich have shown the formation to have a thickness of about 3,500 ft. and have also revealed the presence of thick beds of rock-salt. The latter, with total thickness of over 800 ft., form the basis of an important industry. Up to the end of the last century the rock-salt was extensively mined. Today there is only one working mine, the salt being extracted in solution as brine and mostly converted directly into soda-ash. Northwich, Middlewich, Winsford, Sandbach and Heatley are the main centres of this industry.

In West Lancashire the Keuper Marl forms a wide belt extending from Fleetwood to Formby, though it is largely obscured by a thick mantle of Glacial Drift and other superficial deposits. At Preesall near Fleetwood an important horizon of rock-salt occurs in the Marl, and here also brine is pumped from these measures.

In Yorkshire and Nottinghamshire the outcrop forms a broad belt from the Tees to the Trent, swinging round westwards athwart the southern extremities of the Pennines. In the north the Keuper Marl is about 1,000 ft. thick but is almost entirely concealed by Drift. In Nottinghamshire it is less than 700 ft., but stands out above the Bunter in a marked escarpment; its upper beds contain important deposits of gypsum.

The topmost beds of the Keuper Marl, including the ' Tea-green Marls ', do not lie within the area under description.

Supposed Triassic Rocks in the 'Pocket Deposits' on the Carboniferous Limestone of Derbyshire

Sand and pebble beds which appear to be decolourized Bunter Sandstone, and clays like Keuper Marl, lie in deep pits in the limestone plateau between Longnor and Wirksworth, some five miles north of the main Triassic outcrop. Dark Carboniferous shales, and in places boulder clay, also form part of the fill. The sands are important sources of refractories. The origins of these numerous pits have not been fully explained.

VIII. PLEISTOCENE AND RECENT DEPOSITS

Introduction

NEITHER JURASSIC AND CRETACEOUS nor Tertiary[1] rocks are found in the Pennine uplands. If either of the former ever occurred they have since been removed by denudation; and during the Tertiary period the region appears to have suffered prolonged erosion and to have received, in a rough form, the broad features of its present drainage and topography.

The Pleistocene and Recent deposits are thus the only records of deposition within this area since the Triassic period, and they rest with profound unconformity on all older rocks. Commonly referred to as ' Drift ', they include the unconsolidated clays, sands, gravels and other debris of the Quaternary Ice Age, and the assorted deposits of the Recent, Post-Glacial or Holocene Period, in which we now live.

Classification and History of Deposition

The Glacial Period or Quaternary Ice Age was a remarkable episode in the geological history of the Northern Hemisphere, in spite of its brief duration compared with earlier periods. Its progress was marked by recurrent extensions of enormous ice-sheets, which spread southwards over parts of Britain and its neighbouring seas. These ice-sheets left behind them abundant and easily-recognized traces of their passage: ' perched ' blocks (see Plate XI B), glacier-scratched rock-surfaces, and the ice-moulded 'roches moutonnées' and drumlins; boulder clay and sands and gravels, with their content of far-travelled rocks or ' erratics '; a variety of moraines and other ' constructional ' forms; marginal drainage channels, outwash-fans and valley-trains. Outside the limits of ice-advance were formed ' periglacial ' features: and, after the withdrawal of glacier-ice from Britain, the short record of post-Glacial time was written in peat-bogs, river-deposits, beaches and marine muds, cave-earths and the finds of the archaeologist.

In some areas, for instance the Mediterranean seaboard, a succession of marine Pleistocene strata has been detected; elsewhere, on the mainland of Europe and in North America, four major glaciations are seen to have alternated with milder ' interglacial ' periods. In this country no such clear record exists, and the task of unravelling the evidence for the Pleistocene succession is immensely difficult and is far from complete. Some geologists see evidence of only one glaciation in Britain (the ' monoglacial ' theory was formerly widely held and is entrenched in older text-books), but in most quarters a clear distinction is recognized between Older Drift and Newer Drift.

Older Drift is mainly visible in Yorkshire and the Midlands, south of the line reached by the ice-sheets of the Newer Drift. It comprises no obvious stratigraphical subdivisions, though it may well include representatives of the three older glaciations of the Continent.

Older and Newer Drifts appear to be separated in time by a long interval, for the former was dissected before the latter was deposited. And in part, at least, of this interval the climate appears to have been mild.

[1] A Pliocene fauna was recorded by W. Boyd-Dawkins from a cave near Buxton.

The Newer Drift probably represents the last major glaciation of the Continent; in it, deposits of two different ages are recognized, though the period separating them seems unlikely to have been 'interglacial'.

The inferred sequence of events and of deposits is shown in the table below, the earliest at the bottom: and the reader is cautioned that the evidence on which the table is compiled is incomplete and its interpretation fallible.

Pleistocene and Recent

RECENT OR POST-GLACIAL

Atlantic and Sub-Boreal time

Aggradation of flood-plains and growth of peat.

Boreal and Pre-Boreal time

Formation of post-Glacial terraces: dissection of glacial river-terraces: blown sand formed.

Disappearance of ice from northern Britain and establishment of vegetation: (sub-periods based on climatic fluctuations not detected in the present area).

PLEISTOCENE OR GLACIAL

Newer Drift: Later (York-Escrick) Stage

Extension and regression of ice-sheets: deposition of moraines and outwash-deposits: cutting of marginal drainage channels: formation of Head (solifluxion-drift) in periglacial areas, and partial obliteration of constructional features of deposits of previous stage.

Newer Drift: Earlier Stage

Extension of ice-sheets over northern England, with probable obliteration of Older Drift.

Interglacial Period

Valley-cutting and dissection of Older Drift (South Yorkshire and Nottinghamshire): mild climate during part of period, with deposition of river-deposits with mammalian bones.

Older Drift

Extension of northern ice into the Midlands, with deposition of boulder clay, sand and gravel over wide areas: no detailed sequence of events known.

Deposits Referred to Older Drift

South of the end-moraines of the Newer Drift at York and Escrick there lie, scattered over the slopes of the Pennines (up to about 800 ft. O.D. near Sheffield) and over the lower ground to the east, small patches of boulder clay and, less commonly, of sand and gravel. These appear to be dissected remnants of what were once extensive sheets; in fact, south of Nottingham and just outside the boundary of the area here described, the drifts become part of a widespread blanket of substantial thickness, and are familiar as the Chalky and Chalky-Jurassic Boulder Clay.

They are shown by their lithology to be of northern origin (most of the erratics shown south of Leeds in Fig. 24 belong presumably to the Older Drift); they have lost all features of deposition, and they are apt to show surface-decalcification. No evidence of retreat-stages has been found, and it is possible that the last great ice-sheet of Older Drift times decayed in place. Here and there one sees uncertain indications of marginal drainage channels—the gorges at Creswell Crags and at Kiveton Park, near Worksop, have been cited as examples—but so severe has been subsequent denudation that the origins of these ancient valleys cannot be proved.

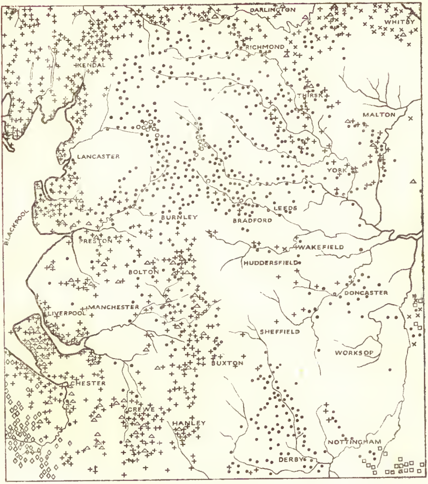


FIG. 24.—*Map showing distribution of glacial erratics in the Pennines and Adjacent Areas.*

(N.B. Cheviot erratics appear to be confined to Yorkshire.)

INTERGLACIAL DEPOSITS

As mentioned above, it is inferred that the interglacial period between Older and Newer Drifts was marked chiefly by valley-cutting and erosion. For example, the deepening of the Aire valley at this time, just below Leeds, appears to have been of the order of 100 ft., and over much of the country to the south the old glacial beds lie perched on hilltops.

Deposits inferred to belong to this interval are the alluvial beds with bones of *Hippopotamus* in Leeds, and similar beds with *Hippopotamus*, *Rhinoceros* and *Elephas* near Nottingham. The situation of these beds with Pleistocene fauna among the valley-bottom alluvia shows that their deposition succeeded the period of valley-cutting.

Newer Drift

The drifts deposited during the two periods of ice-extension shown on p. 68 are distinguished from each other by their topography. That of the later stage is conspicuous for its fresh constructional features, with the characteristic ' tossed ' topography of its moraine-areas to which the modern drainage has not yet adjusted itself, with ice-contact slopes, kettle-holes, drumlins, and the surprisingly clear-cut marginal drainage channels by which melt-water made its way along the edges of the ice. In contrast, the drift of the earlier period shows, at best, only degraded constructional features, and for the most part it is a formless spread of boulder clay, occupying high and low ground alike but, unlike the deposits referred to Older Drift, not deeply dissected. In Yorkshire it appears not to have extended far beyond the Escrick Moraine, and the crescentic belt of gravel-mounds near Wetherby is its only marked feature.

In the continuous plain of south-west Lancashire and Cheshire there are extensive deposits of sands, gravels and silts lying between two Boulder Clays, that are known as Middle Sands. In places the Upper Boulder Clay is overlain by Upper Sands and Gravels.

There can be little doubt that the Upper Boulder Clay and the Upper Sands and Gravels are deposits of the Newer Drift. Most probably the Middle Sands and the Lower Boulder Clay also represent an episode in the laying down of the Newer Drift. The Middle Sands contain well-preserved marine shells, and fragments of shells are found incorporated in the Upper Boulder Clay. Whether the shells in the Middle Sands represent a marine submergence or are to be regarded like those in the Upper Boulder Clay as glacial erratics is an open question. The well-bedded character of the Middle Sands and their great extent certainly indicate deposition in a large body of water. It is probable that the Middle Sands represent an interval between two stages of the Newer Drift but not necessarily an inter-glacial period.

The fact is that the interval between the two stages of the Newer Drift is at present little understood. It cannot confidently be equated with either of the two ' interstadials ' (minor interglacial periods) of the last Continental glaciation; and though the sequence in the cave-earths of Pin Hole Cavern at Creswell Crags near Worksop suggests three cold phases with two temperate or moderately warm intervals, there is no means of correlating this sequence with that of the Yorkshire Pleistocene, except that it is clearly younger than the Older Drift. A strand-line in the Vale of York at 100 ft. O.D. is perhaps of this age, though it does not correspond with what is known of sea-levels at comparable stages of the Pleistocene elsewhere in Britain.

During the Newer Drift Glaciation the ice accumulated in the north-west. The Southern Uplands of Scotland, the Lake District, and the Northern Pennines all contributed their quota to form an ice-sheet which moved generally southwards and wherever possible eastwards. The main southern escape was by way of the Irish Sea. This ice-sheet split against the Welsh mountains, and an eastern tongue invaded the low ground of Lancashire and Cheshire and pushed southwards to beyond the Dee-Severn watershed.

The Pennines, however, were crossed at many places. Ice from the Lake District and Southern Scotland swept across the Tyne Gap into Northumberland and Durham, where it was joined by local glaciers nourished on the Alston Block and by the northern ice from the Cheviots. Farther south another strong stream of Lake District ice crossed from Edenside by Stainmore into Teesdale. Thence it moved down the Vale of York, uniting on the one side with northern ice which was streaming round both sides of the Cleveland nunatak and on the other with glaciers from the Yorkshire dales. These extended southwards to the neighbourhood of York and Escrick.

A strong ice-stream flowed directly southwards from the southern part of the Lake District. Inland it was united with ice moving through the Lune Gap from Edenside, with Howgill Fell ice and farther inland with Upper Ribblesdale ice. The latter crossed the Pennines by the Aire Gap and gave rise to the well-developed drumlin suite of the Settle-Skipton area.

Farther south a lobe of ice almost crossed the Pennines near Buxton into the Wye Valley, following the track of the Older Drift invasion.

These movements are deduced essentially from the boulder-content of the Newer Drift. Thus the drifts of the low-lying Cheshire-Lancashire plain contain Dalbeattie and Criffel granites from Galloway, and Ennerdale granophyre and Eskdale granite as well as Borrowdale Volcanics from the western Lake District. The ice that crossed Stainmore is characterized by Shap granite and Brockram from the Vale of Eden, whilst the Ribblesdale glacier gave rise to drifts which contain only local erratics such as gritstone, limestone and a comparatively rare Lower Palaeozoic grit.

To the west of the Pennines during the early stages of the recession of the ice, one margin of the ice-sheet was banked high against its western slopes. Later the ice held up a system of glacier-lakes against these mountains, the waters from which eventually crossed the main watershed to augment such rivers as the Trent and the Yorkshire Calder. As the ice-front receded into the lowlands it left an abundance of retreat-phenomena in the form of marginal drainage channels, overflows, and sand and gravel mounds too numerous to detail. As an example, the overflow-channel at Littleborough is shown in Plate XI A.

In general the recession of the ice-front was westwards into the Lancashire-Cheshire Plain and in that plain northwards towards the Lake District. This plain is the area *par excellence* of the Middle Sands—large spreads of sand and gravel capped by Boulder Clay. As already mentioned they are water-lain and probably accumulated during a recession of the ice which was subsequently followed by a local forward surge. The final clearance of the ice from these lowlands is marked by an extensive glacier-lake which drained southwards by the Ironbridge Gorge into the lower Severn drainage. Land-stream deltas of gravel were deposited in this glacier-lake. At this stage the ice in the north had shrunk into recognizable valley-glaciers on the south side of the Lake District, although to the north of that massif the Carlisle Plain and the Irish Sea as far south as the Isle of Man was probably still occupied by thick ice. To complete the story in the north-west: there is evidence of an oscillation of the ice-front near Gosforth south of Whitehaven, and later the final clearance of the ice from the Carlisle Plain was interrupted by a local re-advance of some magnitude. During the time of the latter re-advance small corrie-glaciers occupied the mountainous areas of the northern part of our region.

East of the Pennines there is no evidence of a consistent development of ' Middle Sands ' in the Newer Drift, and such sands and gravels as occur lie amongst stony moraines and stiff boulder clays in seeming disorder. Recession of the last ice sheet was, to a considerable extent, periodic. The two moraines of Escrick and York are about six miles apart, and there are other, less defined, morainic belts farther north that seem to mark temporary halts of the retreating ice. Retirement of the valley-glaciers of the Yorkshire Dales left a series of prominent frontal moraines: some of these are associated with valley-trains, and some so obstructed drainage as to hold up temporary lakes which have since become filled with clay and silt. Marginal drainage was much in evidence, and produced complex systems of lateral channels as the unsteady withdrawal of the ice constantly laid bare new avenues of escape for the waters ponded back in lateral valleys and embayments. The channels between Ripon and Wetherby, by which water impounded along the eastern slopes of the Pennines escaped southwards, are of particular interest: they effected the permanent diversion of the River Nidd at Knaresborough and the Wharfe at Boston Spa, both rivers breaching the Permian limestone in peculiar, misfit gorges which give a rare distinction to the scenery of these two localities.

Periglacial Deposits of the Newer Drift

Of uncommon interest are the assorted drifts which were produced during the last glaciation, in areas which, though not invaded by the ice, suffered the rigours of the glacial climate. They may conveniently be classified under the following heads:—

Fluvio-glacial sands and gravels, valley-trains and river-terraces.—Melt-water from the ice-sheets was for a time a potent agent in the distribution of glacial debris, and spread out sheets of sand and gravel over the low ground beyond the glaciers. In the Yorkshire Dales the moraines of the retreat-stages tend to be followed downstream by ' valley-trains ' (inclined sheets of ill-sorted debris thrown down by water issuing from the ice-fronts), which pass downstream into ' normal ' river-terraces of gravel and sand; it appears that most of the terraces of these rivers have originated thus, and are only ' post-glacial ' in the sense that they were deposited after the cessation of local glaciation along their courses. Bulky terraces along the river Trent are also fluvio-glacial, but in this instance appear to consist of debris (mainly Bunter Pebble Beds) provided by the cutting of an escape-channel by Irish Sea drainage-water at the head of the catchment (outside the area here described) and by the fierce scour of the great flood so induced.

Water-lain drifts of the Vale of York.—During the period of final deglaciation the Vale of York was occupied by shallow water (whether related to high sea-level or to blockage of the Humber estuary—the ' Lake Humber ' of Carvill Lewis—is uncertain). The great thickness of bedded and laminated clays, with silts and sands—the ' Warp and Lacustrine Clay ' of the old geological maps—which fills up the southern part of the Vale to about 25 ft. O.D. was probably derived from melt-water flowing from north, north-east, west (the Calder), and south (the Trent), augmented by muddy water from rivers running off the unglaciated areas but themselves choked with the products of solifluxion (see below). These sediments cover an old surface of some relief, with hollows extending to well below sea-level. A strand-line at a higher level, marked on both sides of the Vale of York by patches of locally-derived gravel at and below 100 ft. O.D., is perhaps of earlier age (p. 70).

Head (*Solifluxion-Drift*).—Sheets of unbedded stony clay, attributed to solifluxion under sub-glacial conditions, probably on a permanently frozen subsoil or ' permafrost ', are common outside the limits of the Newer Drift ice. In tributary valleys they grade into the valley-trains and so betray their age: occasionally they are seen in sections to interdigitate with water-lain sands and gravels: in the upland areas of Millstone Grit they form great spreads on the slopes of hills, and are commonly charged with blocks of grit up to 20 ft. across, which here and there are so numerous as to form ' stone-rivers '.

Occasionally, wind-etched stones are found in the Head, as if wind-action and solifluxion were closely related in time, perhaps in seasonal alternation.

Wind-etched stones.—Sculptured and faceted stones—dreikanter, ventifacts or aeoliliths—owing their characteristic shapes to sand-blast, lie about the fields in the neighbourhoods of Manchester and Pendleton and over wide areas of Yorkshire and the East Midlands south of the Escrick Moraine. Although those in Lancashire, and probably many east of the Pennines as well, are post-Glacial, in Yorkshire some are of earlier age, and appear to have been formed under the cold, dry conditions of the periglacial belt. Near Pontefract a ' pavement ' of these stones (several fine examples are in the Museum of Practical Geology) underlies the water-lain drifts of the Vale of York; and scattered specimens have been found in Head (see above). Other probable effects of wind-driven sand are the undercut stacks of sandstone which are familiar landmarks on the Millstone Grit moors.

POST-GLACIAL AND RECENT DEPOSITS

No hard and fast line divides these beds from the Glacial, particularly in this region of rudimentary chronology. The deposits of the rivers Lune and Ribble are well-bedded river gravels that are definitely post-Glacial, and the deposits of the Mersey and Irwell, although probably commencing whilst ice occupied parts of the Lake District, are post-Glacial in the sense that the waters which laid them down were not augmented by glacier melt-waters. Some of the river-terraces in Yorkshire are probably of like age, though, as stated above, many are contemporary with the waning of the last ice-sheet. Landslips in the deep valleys of the Millstone Grit country appear, on the whole, to be recent: many, indeed, are still in motion, for example at Mam Tor, where the great slips shown in the foreground of Plate VII B are continually sweeping away sections of the road between Sheffield and Chapel en le Frith. The blown sands of Lancashire and Cheshire are post-Glacial, and their formation has continued until recent times. Inland they are thin, sporadic and featureless as in the case of the Shirdley Hill Sands. Dunes along the coast near Formby and Southport have overwhelmed large tracts within the historical period, and dreikanter have been formed in recent times in such areas.

Cave-deposits which have been examined in the limestone districts have yielded for the most part a post-Glacial fauna with traces of occupation by man; but the lower levels of certain caves, e.g. Pin Hole at Creswell Crags (p. 70) and Victoria near Settle, show evidence of earlier, Pleistocene occupation. Bones of elephant, rhinoceros, reindeer, hyaena and other animals which once roamed this country are a feature of the cave-earths; likewise the implements of Palaeolithic (at Creswell), Mesolithic and Neolithic man.

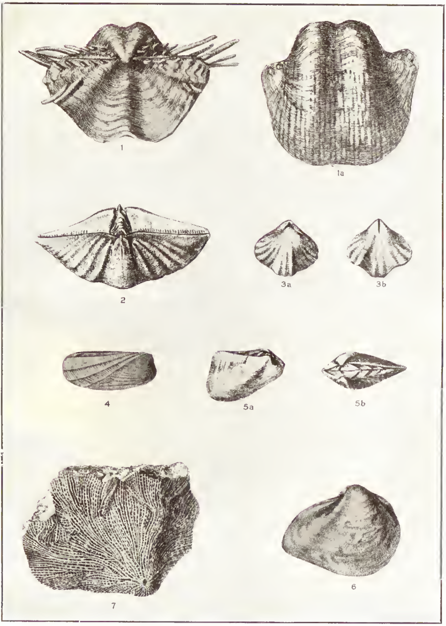
A submerged forest is found in the estuaries of the Dee and Mersey and also occurs at intervals northwards to the Solway Firth. It consists of peaty deposits with trunks and stools of oak, alder and willow, with much marshy vegetation and with bones of animals such as red deer. A well-known example crops out on the foreshore between Hightown and Blundellsands, and another at Dove Point, Leasowe. These beds indicate a period of low sea-level, probably of Mesolithic date, which preceded formation of the 25-ft. raised beach of Neolithic age.

Forest trees also lie beneath the alluvium of the rivers Aire and Calder in Yorkshire, and are notable for their large size. They probably date from the Atlantic period.

Peat-mosses occur in the flat lowlands, e.g. Chat Moss near Manchester and the 'wastes' of Thorne and Hatfield in Yorkshire; also on the Pennine moorlands above 1,000 ft. O.D., where they are about 6 ft. thick on the average and consist of remains of cotton-grass and of a few other plants. The bulk of the peat, both upland and lowland, is post-Glacial, and its lower layers, even high on the Pennines, contain trees such as birch and alder. In many Pennine areas there occur beneath the peat small flint implements and chips, recognized by archaeologists as characteristic of the Mesolithic period; but some of the peat is older, for an arctic flora has been found at its base in the northern Pennines.

Tufa is common in the Craven district of Yorkshire and in the Derbyshire Hills, indeed everywhere where limy springs are depositing their calcium carbonate. Similar stalagmitic layers occur in caves (Plate IX A), and at Creswell a number of such appear to be of Glacial date.

Alluvium, occupying the flood-plains of the rivers, is the most extensive of the Recent deposits; and like tufa and, in some areas, peat, is being added to at the present day.



MAGNESIAN LIMESTONE FOSSILS
(All natural size.)

Reproduced from W. King, ' Monograph of the Permian Fossils of England ', by permission of the Council of the Palaeontographical Society.

1., 1*a*. *Productus* (*Horridonia*) *horridus* J. Sowerby; two shells, one showing spines.
2. *Spirifer alatus* (Schlotheim); internal cast.
3*a*, 3*b*. *Stenoscisma* [*Camarophoria*] *schlotheimi* (von Buch); two views.
4. *Pleurophorus costatus* (Brown).
5*a*, 5*b*. *Bakevellia antiqua* (Münster); two views.
6. *Schizodus obscurus* (J. Sowerby); internal cast.
7. *Fenestella retiformis* (Schlotheim).

(For description, *see* p. v) (A 2530)

A. THE SUMMIT GORGE, LITTLEBOROUGH

(For description, *see* p. v) (A 7599)

B.—PERCHED BLOCK, NORBER, NEAR AUSTWICK

IX. STRUCTURE

THE STRUCTURES in the region result from three major earth-movements, the Caledonian, the Hercynian, and the post-Triassic which is presumably of Tertiary age.

Caledonian Movements

The Caledonian movements took place before the deposition of the Carboniferous, and their effects are seen in our region only in the older Palaeozoic rocks of the Howgill Fells – Sedbergh area. In this area the Caledonian movements have given rise to acute folds of east-north-easterly trend, and locally the compression was sufficiently intense to develop a pronounced cleavage of similar trend.

Hercynian Movements

The second period of great earth-movements took place after the deposition of the Carboniferous. There is evidence of precursors to the main movements in the presence of several intra-Carboniferous unconformities (see for example the unconformities to the south of the Rigid Block in Fig. 8). These precursors, however, are insignificant in comparison with the main movements. During the main movements the dome-like Howgill Fells Anticline, which involves Carboniferous Limestone on its northern and southern flanks, was formed. It was separated from unfolded, but relatively depressed, strata to the east by the Dent line—a zone of complex faulting with an easterly downthrow. This unfolded area is known as the Askrigg ' Massif ' or Block, and just as the Dent Line defines its western margin so the Craven Faults define its southern margin (see Fig. 8).

During Hercynian times this Block was dominated in the south by the complex anticlinal uplift now known as the Ribblesdale Fold-belt. This important structure of west-south-westerly trend crosses the present watershed of the Pennines, and extends westwards to the neighbourhood of Preston where it plunges beneath the Permo-Triassic rocks. Borings would appear to indicate that it extends still farther westwards beneath these rocks to the neighbourhood of Southport.

Included in the Ribblesdale Fold-belt are the anticlines of Slaidburn, Clitheroe, Skipton (see Plate XII) and Harrogate.

To the north of the western part of the exposed Ribblesdale Fold-belt there is the complex syncline of the Lancaster Fells, which is also complementary to the Howgill Fells Anticline already mentioned.

The southern member of the Ribblesdale Fold-belt is the steep Pendle Monocline that extends for a distance of more than twenty miles past Blackburn to beyond Colne, and involves about 5,000 ft. of Upper Carboniferous rocks, mostly Millstone Grit, dipping at 40° to 60° to the south-south-east.

In Yorkshire these acute east-north-easterly trending folds do not extend far south. In Lancashire, however, they persist southwards but with decreasing intensity. Thus the Coal Measures of the Burnley Syncline lie between the Millstone Grit outcrops of the Pendle Monocline and the Rossendale Anticline; and father south the South Lancashire Coalfield lies in a second syncline the southern part of which is partially obscured by the Permo-Triassic rocks of Cheshire.

The dissimilar structures of Yorkshire and Lancashire are separated from one another by a north-south fold line, the so-called Pennine Anticline. From its axis the Millstone Grit strata dip relatively steeply to the west at

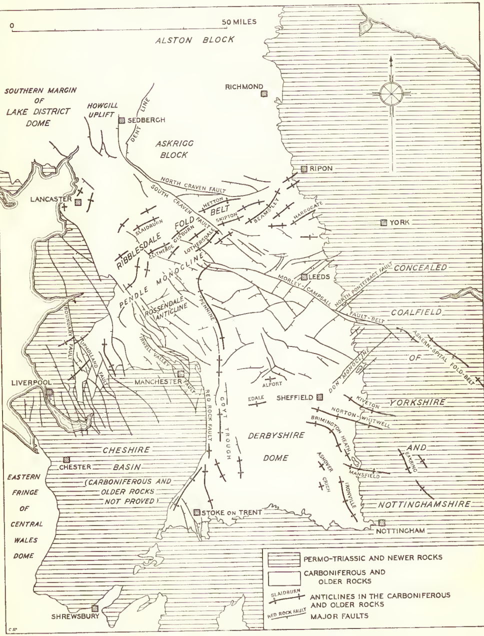


FIG. 25.—*Structure-map of the Pennines and Adjacent Areas.*

angles of 20° to 40° and gently to the east (see Plate XII c). This somewhat unimpressive anticlinal structure develops southwards into a number of pronounced folds (see Plate XII D) of which the synclines are, by reason of their contained coalfields, more familiar than the anticlines. Such are the Goyt Trough and, just beyond the south-west boundary of our region, the basins of the Cheadle and North Staffordshire coalfields. This belt of north-south folding abuts on the Carboniferous Limestone of the Derbyshire ' Massif ' much as does the Ribblesdale Fold-belt on that of Askrigg.

Both these ' massifs ' played a similar part in the sedimentation of the Carboniferous rocks (see p.18): but the Derbyshire ' Massif ' is, so far as can be seen, much the smaller and, unlike that of Askrigg, takes part in the folding. Further, the rocks lying against its western and northern margins are much less acutely folded than those bordering the Askrigg Block. Both the southern and eastern margins of the Derbyshire ' Massif ' are indefinite, but on the north it terminates at Castleton in a spectacular scarp beyond which the Upper Carboniferous rocks are gently folded.

The Carboniferous rocks east of the Pennines and south of the Ribblesdale Fold-belt show a simplicity of structure which is in strong contrast with that of the west. The measures of the Yorkshire and East Midlands Coalfield (which have been explored beneath the Permo-Trias far beyond the River Trent) dip very gently in from their outcrop as towards the bottom of an extremely broad and shallow basin—though nowhere has an eastern limit to such a basin been found. A few small anticlines rise from one to two thousand feet above the general level and, with the exception of the north-easterly trending Don Monocline, show a roughly Charnian (north-north-westerly) alignment. Faulting is general throughout the area, but the throws of individual faults seldom exceed 500 ft.

Post-Triassic Movements

It is probable that more than one major earth-movement is represented in the structures that can be shown to be of post-Triassic age.

The overall pattern portrayed by the post-Triassic movements is one of domal elevation of structural units in the west, combined with north-south elevation along the line of the Pennine axis, where, however, there also appears to have been some differential movement of pre-existing structural units.

The Lake District and Central Wales are the two western domal elevations and both lie outside our Region. But their intervening syncline (which is not a simple downfold but is wrinkled by minor east-west folds) is apparent in our Region along the whole of the coastal belt of Lancashire.

In dealing with the north-south elongation of the Pennines we must also look beyond our Region. The elevation of the Askrigg ' Massif ' or Block is linked with that of its counterpart the Alston Block to the north. Both are elevated along lines of faulting that involve Permo-Triassic rocks and both are tilted gently eastwards.

Along the line of the Pennines between the Askrigg Block and the Derbyshire ' Massif ' or Dome the evidence of elevation in post-Triassic times is more apparent to the east than to the west. To the east there is the continuous outcrop of Permo-Triassic and younger rocks, whilst to the west the evidence is limited to small outliers such as that of Clitheroe and to the northward prolongation from Stockport to Bolton of the Cheshire Basin. Farther south, however, there is ample evidence of post-Triassic uplift around the Derbyshire Dome. The continuous spread of Permo-Triassic rocks sweeps southwards and then westwards around its southern flanks to join up with similar rocks in the Cheshire Basin. The latter is the deep downfold which lies between the Derbyshire Dome and the Central Wales Dome.

It will be noted that the impress of the post-Triassic elevation is broadly stamped upon the topography of the country. The domes and anticlines are mountainous areas whilst the downfolds or synclines are areas of low relief.

Nevertheless, the overall picture is considerably modified by tensional post-Triassic faults which are abundant and of considerable magnitude in the west, on the flanks of and between the elevated structural units. Only a small number, however, are directly related to the uplifted structural units, and of these the North Craven Fault may be quoted as an example. The majority have a regional north-westerly to north-north-westerly trend. They are particularly abundant in the Lancashire Coalfield, and persist into Cheshire where for the most part, however, they cannot be followed because of thick drift and lack of underground information. Nevertheless, it is significant that recent borings on a close grid in the Mobberley region of Cheshire proved a fault downthrowing about 2,500 ft. to the north-east.

A north-westerly trending fault-belt some 6 miles wide passes through Manchester. In it the Irwell Valley Fault, with a maximum downthrow of 3,000 ft. to the north-east, is the most important fracture. Other fractures of this belt which attain throws in excess of 1,000 ft. are: Oldham Edge, Chambers, Ashton Moss, Bradford, Outwood and Pendleton.

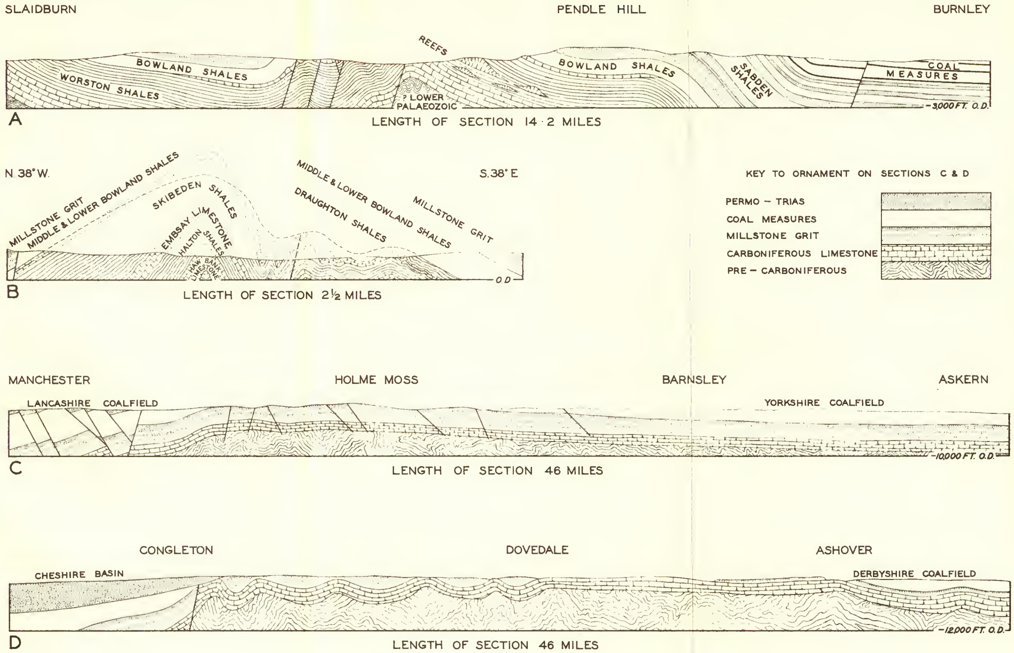
Another north-westerly fault-belt of comparable width passes through Wigan, and includes the following faults with maximum throws in excess of 1,000 ft.: Great Haigh, Shevington, Pemberton, Bryncrop and Warburton. Farther west the Eccleston Trough lets down Permo-Triassic rocks, the two bounding fractures having throws of the order of 1,500 ft. Farther north the Downholland Fault attains a maximum downthrow of 4,000 ft. to the south-west.

The Boundary Fault separates Keuper from Bunter in the Fylde, where its westerly downthrow cannot be less than 3,000 ft. Farther south it separates Coal Measures and Bunter with decreasing throw, until in the neighbourhood of Knowsley it is of the order of 1,000 ft. Of the same order of magnitude is the Red Rock Fault, which, along a considerable part of its course, separates the Trias of the Cheshire Basin from the Carboniferous of the Pennine country to the east.

Pronounced variability in the amount of throw is a feature of these post-Triassic faults of north-westerly trend.

East of the Pennines the chief effect of post-Triassic movement is a gentle easterly tilt, generally at less than 1 in 100. Contours on the Permo-Triassic base (Fig. 18) show this tilt to be remarkably uniform and little affected by big faults. Such faulting as exists is partly due to resumption of movement along the earlier, Hercynian, displacements. The throws of these faults are seldom great; that of the North Pontefract Fault is between 100 and 150 ft, and other substantial movements are apparent in the displacement of the Permo-Triassic base at South Elmsall, Hampole and Conisbrough near Doncaster and at Kiveton Park and Barlborough east of Sheffield.

PLATE XII



CROSS SECTIONS OF PENNINE FOLDING, NATURAL SCALE

A. NORTH-WEST TO SOUTH-EAST SECTION ACROSS THE RIBBLESDALE FOLD BELT. B. FOLDING IN THE CARBONIFEROUS LIMESTONE SERIES OF THE SKIPTON ANTICLINE: ADAPTED FROM HUDSON AND MITCHELL. C. WEST TO EAST SECTION ACROSS THE PENNINE ANTICLINE. D. WEST TO EAST SECTION ACROSS THE SOUTHERN PENNINES: ADAPTED FROM LEES AND TAITT.

THE LOWER PARTS OF SECTIONS C AND D ARE BASED ON INFERENCE (THE FOLDING SHOWN IN THE PRE-CARBONIFEROUS IS A CONVENTIONAL PATTERN)

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X. ECONOMIC PRODUCTS

THE REGION includes some of the greatest industrial districts in Britain, and its rocks yield a variety of products which are important, not only to its own economy but also to that of the rest of the country.

Coal.—With an output of roughly 2,000,000 tons a week the region provides nearly half of Britain's coal. Some three-quarters of this amount come from the coalfield of Yorkshire and the East Midlands, which is an area of rising production and which has very large reserves (an interim estimate by the Ministry of Fuel and Power is in excess of 10,000 million tons). The area over which the major seam, the Barnsley or Top Hard, has been proved in workable condition is more than 700 square miles, though substantial parts of this are now exhausted and production from other seams is becoming relatively more important.

Several varieties of bituminous coal are worked—house, gas, coking, industrial; much locomotive coal is got from the durain-rich beds of 'hards' in such seams as the Barnsley, Parkgate and Beeston in Yorkshire and Top Hard and Deep Hard in the East Midlands. To a less extent the 'top hard' coal of the Trencherbone seam of Lancashire is selected and marketed separately.

The region contains coals with volatile-content ranging between about 34 and 42 per cent and carbon-content between about 80 and 87 per cent.

Oil.—Seepages of oil are occasionally encountered in colliery-workings and borings in all the coalfields; exudations of bitumen or 'elaterite' have long been known in the Carboniferous Limestone of North Derbyshire, for instance in the vicinity of Castleton; and liquid oil is often found in the body-chambers of goniatites embedded in 'bullions'.

These indications appeared sufficiently promising to justify a search for oil at the end of the first World War. Several borings were made on visible anticlines and carried down to the Carboniferous Limestone, but only at Hardstoft in East Derbyshire was there a yield. It came from the top of the Carboniferous Limestone at about 3,000 ft. and was being pumped until recently, though at a diminishing rate.

In 1936 a more intensive search was begun, and was preceded by geophysical prospecting. Using seismic methods, the D'Arcy Exploration Company found a composite anticline in Carboniferous rocks at Eakring in Nottinghamshire, deeply buried beneath the Permo-Trias. Oil was struck in the first boring in the year 1939, and proved to be one of three considerable accumulations in the Upper Carboniferous sandstones of this area, some 2,000 ft. beneath surface. By 1949 over 592,000 tons had been produced, more than 250 wells having been drilled.

Of interest is the discovery of mineral oil in the vicinity of Formby in West Lancashire. More than a century ago oil seepages had been observed in some of the peat mosses of this region, but their significance appears to have been overlooked until the investigations made in this district by Cope in 1937. Around Formby thick drift overlies the Keuper Marl and sandstones, and borings made on Downholland Moss encountered Keuper sandstones, impregnated with mineral oil, at a depth of 125 ft. These shallow borings produced, and have continued to produce, relatively small quantities of oil of the order of 2,000 gallons a week. A deep-seated source of the oil has been sought but so far without success.

Ironstone.—The clay-ironstone which was worked until recently (p. 4) occurs as nodular layers in the mudstones of the Coal Measures, some of the best-known of such layers being in the measures of the *modiolaris* Zone. The workings, mainly at or near outcrop, covered wide areas, and the disturbed ground left by them is still conspicuous in places.

Lead and zinc.—Veins carrying the ores of these two metals are common in parts of the Lower Carboniferous rocks of Derbyshire and the Northern Pennines. They occur chiefly in vertical veins or ' rakes '; in ' pipes ', which are elongated masses of ore, both horizontal and vertical; in ' flats ', which are usually replacement-deposits along particular beds of limestone; and in random bodies which conform to no particular grouping. Shales such as the Edale Shales, and in Derbyshire the beds of igneous rock, form ' cap-rocks ' which controlled the emplacement of ores.

The chief ore is galena (lead sulphide). Blende (zinc sulphide) is subordinate but is locally important; calamine (zinc carbonate) also occurs; and the weathering-products cerussite (lead carbonate) and hemimorphite (zinc silicate) come chiefly from the higher levels of mines.

Lead has been mined in the Pennines since Roman times, but production was greatest in the second half of the eighteenth century; most of the readily accessible ore has now been got, and at the time of going to press very little lead is being raised though the mining of fluorspar and other minerals is important (see below).

Copper.—The common ores of copper have been worked in the past, mainly in the Keuper Sandstone at Alderley Edge in Cheshire (where some of the workings are prehistoric) and in the Carboniferous Limestone at Ecton near Leek. Small occurrences are recorded from several other localities in the Pennines and adjacent areas.

Fluorspar, barytes, witherite, and other gangue-minerals of the lead-zinc deposits.—The above minerals occur with calcite, some wad (black oxide of manganese), ochre, and in the Northern Pennines ankerite and allied carbonates; and they form part, and often the principal part, of the content of the veins and other ore-bodies described above. Fluorspar (calcium fluoride) is particularly important in Derbyshire, in a zone on the east side of the mineral field including the inliers of Ashover and Crich. It is being worked from old dumps and from a number of reopened mines in an effort to meet an expanding demand. Less productive areas have been worked in the higher parts of Swaledale and Wensleydale and near Pateley Bridge. The variety called ' Blue John ' has been mined near Castleton in Derbyshire for ornamental use (a fine vase is exhibited in the Museum of Practical Geology).

Barytes (barium sulphate) occurs in Swaledale, Wensleydale and upper Airedale; also in the mineral field of Derbyshire, in a belt about 3 miles wide on the west of the fluorspar zone. In both areas it has been mined extensively. Witherite (barium carbonate) has been recorded with barytocalcite in small amounts from many localities in West Yorkshire, and it was worked farther north in Durham. Strontianite (carbonate of strontium) occurs in small quantities near Reeth in Swaledale.

Gypsum and anhydrite.—Gypsum is common in the Middle and Upper Permian Marl east of the Pennines, and has been worked at Hillam east of Leeds; also in the higher parts of the Keuper Marl of Nottinghamshire, just south of the area here described. Anhydrite has been found in the Permian beds in several deep borings to the north and north-east of Doncaster.

Salt.—Thick beds of rock salt in the Keuper Marl of Cheshire and Lancashire have given rise to an important chemical industry. Formerly obtained by mining, rock salt is now almost entirely extracted as brine, dissolved from the salt beds by the controlled pumping of water. Over two and a half million tons or more than 82 per cent of the total salt output of Great Britain are obtained in Cheshire. The only salt mine still producing is that at Winsford, where 40,000 tons were produced in 1947. Some 27 per cent of the total brine output is evaporated to give white salt, and the remainder is used as brine in the manufacture of chemicals. Rock salt in the Preesall area of Lancashire has been exploited since 1889, and is now extracted exclusively as brine for the chemical industry. The annual production of brine at Preesall contains over 300,000 tons of salt.

Salt has been proved in a boring near Selby, Yorkshire, and is abundant farther to the north-east.

Fireclay and ganister.—Certain seatearths in the lower part of the Coal Measures, e.g. the Pot Clay in South Yorkshire, are refractory, and are worked both opencast and in mines. Ganister, which is a highly siliceous seatearth found in the same measures and also in the Millstone Grit, is less readily mined, and the more accessible occurrences of the best beds, such as that below the Ganister Coal near Sheffield, are exhausted.

Dolomite.—In some areas the higher beds of the Lower Magnesian Limestone on the east of the Pennines are nearly pure dolomite. They are worked on a large scale near Worksop and Doncaster, and processed into basic refractory materials. Other uses of the Permian limestones are given below.

Stone.—The traditional building arts based on the use of local material have fallen into disuse, and much of the stone quarried is for special purposes and is often sent out of the district.

The sandstones, grits and slates of the Lower Palaeozoic and Ingletonian rocks in the north-west, formerly much used locally, are now exploited for road-material. The Carboniferous Limestone Series yields some excellent freestone, a famous variety being the crinoidal Hopton Wood Stone of Derbyshire; but most of the limestone quarried—in 1947 Lancashire produced 941,000 tons and Derbyshire 4,246,000—is used in chemical processes such as the manufacture of soda-ash, also for agricultural lime, glass and cement. The Millstone Grit has provided much massive stone, such as that named after Bramley Fall near Leeds and Darley Dale or Stancliffe in Derbyshire. Millstones are made, seldom now for grinding corn, but commonly to grind wood for paper and cork for linoleum. Flagstones from the Haslingden Flags in Lancashire and the Rough Rock Flags in Yorkshire have been wrought extensively, tilestones less so. The sandstones of the Coal Measures include a number of valuable freestones and flagstones, mainly from the lower parts of the succession. Grindstones for edge-tools come from higher beds, such as the Woolley Edge, Ackworth and Wickersley rocks in Yorkshire.

The Lower Magnesian Limestone of Yorkshire and the East Midlands has provided much beautiful freestone, seen to advantage in many a medieval church and abbey. Its chief use at present is for dolomite (see p. 81) and for burning to builders' lime. The Upper Magnesian Limestone of West Yorkshire, almost dolomite-free, is burnt to agricultural lime. The Triassic sandstones, though generally softer than those already mentioned, have been much used in the past, especially on the west of the Pennines. Keuper Sandstone is being quarried at Storeton in the Wirral peninsula, and the red Bunter sandstones of Rainhill and Woolton in West Lancashire have been used with good effect in Liverpool and the neighbouring towns.

Clay for bricks, pottery, etc.—A strong type of brick for building and engineering is made from the mudstones and siltstones in the Upper Carboniferous rocks, particularly in the Coal Measures. Accrington is a notable centre of the industry in Lancashire, and brickworks are scattered widely over the Yorkshire Coalfield. The Keuper Marl around Nottingham is also used for bricks. Pottery clays are, or have been, obtained from seatearths at certain horizons in the Coal Measures, especially at Denby and Pye Bridge in Derbyshire and Swinton Pottery near Rotherham in Yorkshire. Bulwell near Nottingham produces flower-pots, using the Middle Permian Marls of the Permo-Trias. ' Clay ' for cement is worked in the Edale Shales at Hope in Derbyshire.

A parting of clay in the Stanley Main Coal near Wakefield is a source of alum: and laminated clay in the drift is dug on a small scale for stemming shot-holes in collieries.

Sand and gravel.—To some extent the coarse sandstones in the Millstone Grit are crushed for building purposes. Sands in the Permo-Trias are also used, and this formation includes as well some excellent moulding-sands. Glacial drift is an important source of building sand and gravel, especially on the west of the Pennines where numerous rather small quarries are worked. The gravel taken from large excavations along the Trent valley and near Doncaster contains a large content of quartzite, derived from the Bunter Pebble Beds. Shirdley Hill Sand, a deposit of Recent blown sand, is dug extensively for glass-making in the Liverpool/St. Helens area.

Ancient glass-works at a number of places appear to have used local sources of sand, e.g. Glass Houghton near Pontefract, close to the outcrop of the Basal Sands of the Permo-Trias.

Water supply.—The uplands of the Millstone Grit have been almost wholly appropriated for catchment-areas, and the many reservoirs between Wensleydale and the Derbyshire Hills cater for large industrial areas on both sides of the Pennines. The softness of this water has been an important factor in the location of the textile industries of Lancashire and Yorkshire.

In some cases good supplies of water have been got from the coarse sandstones in the Millstone Grit and Coal Measures, but on the whole these are not highly permeable. The Triassic sandstones, on the other hand, are of great importance both in the east and the west; the Bunter Sandstone, in particular, is a very permeable rock giving large yields of moderately soft water. Public water supplies in the lowlands are drawn heavily from this formation, estimates of daily yield being about 50 million gallons in West Lancashire and Cheshire and 20 million in South Yorkshire and Nottinghamshire: and in addition there are many wells serving factories, mines and private users. Overpumping has become a problem in some areas, and there exploitation is now under statutory control.

By comparison, the water in the Keuper is hard, owing to solution of gypsum; it is largely used for the brewing of beer.

Of the many 'spas', located on springs with water containing unusual concentrations of mineral salts, those of Buxton, Matlock and Harrogate are well known. Buxton, the Roman 'Aquae', has warm springs—82° Fahrenheit—which are notably radioactive. Salt water issued from the Carboniferous Limestone in an oil-boring at Ridgeway near Sheffield at 120° F.

XI. MAPS AND MEMOIRS OF THE GEOLOGICAL SURVEY, AND SHORT LIST OF OTHER WORKS

MAPS AND SECTIONS

Quarter-Inch to One Mile—

Colour-printed; Solid Edition. Nos. 3, 4, 5 (with 6), 7, 9 (with 10), 11.

One Inch to One Mile—

Many of these are published in 'solid' and 'solid with drift' editions; a few in 'drift' editions. The Old Series maps are hand-coloured and are not now in print (those replaced by New Series maps are obsolete and are not listed). The New Series maps are colour-printed. Those marked with an asterisk are on sale at the time of going to press; others are being reprinted.

NEW SERIES

42 (Northallerton)*; 52 (Ripon and Thirsk)*; 62 (Harrogate); 63 (York)*; 68 (Clitheroe)*; 69 (Bradford)*; 70 (Leeds)*; 71 (Selby)*; 74 (Southport)*; 75 (Preston)*; 76 (Rochdale)*; 77 (Huddersfield)*; 78 (Wakefield)*; 83 (Formby)*; 84 (Wigan)*; 85 (Manchester)*; 86 (Glossop)*; 87 (Barnsley)*; 96 (Liverpool)*; 97 (Runcorn)*; 100 (Sheffield)*; 110 (Macclesfield and Congleton); 112 (Chesterfield); 113 (Ollerton)*; 125 (Derby and Wirksworth); 126 (Nottingham and Newark)*; Special Sheet (Nottingham District); 140 (Burton-upon-Trent)*; 141 (Loughborough)*.

OLD SERIES

The following sheets have been replaced by New Series maps:—71, 72 S.E., 79 N.E., S.E., 82 N.W., S.W., 87 N.W., S.W., 88, 89, 90, 92, S.W., S.E., 93.

For the areas where no New Series maps have been published, the following Old Series maps should be consulted: 70 (Grantham); 72 N.E. (Ashbourne and Dovedale); 73 N.W. (Whitchurch and Malpas); 80 N.E. (Altrincham and Knutsford); 80 S.W. (Chester and Tarporley); 80 S.E. (Northwich); 81 N.W. (Stockport); 81 N.E. (High Peak); 81 S.E. (Buxton and Bakewell); 82, 91 N.E. (Lancaster and Carnforth); 91 S.W. (Blackpool and Fleetwood); 91 S.E. (Garstang); 92 N.W. (Settle and Malham); 92 N.E. (Pateley Bridge and Grassington); 97 N.W. (Kirkby Stephen and Mallerstang); 97 N.E. (Richmond and Reeth); 97 S.W. (Whernside and Ingleborough); 97 S.E. (Bedale and Masham); 98 N.E. (Kendal and Sedbergh); 98 S.E. (Kirkby Lonsdale).

Six Inches to One Mile—

The greater part of the region is also represented by geological maps on the six-inch scale. For practically all the areas where Coal Measures are exposed the maps are published, with geological lines inserted. The six-inch maps of the other areas are deposited for reference in the library of the Geological Survey, Exhibition Road, South Kensington, S.W.7, where they may be consulted. Copies of these can also be supplied to order.

Vertical Sections—

Sheets 27, 28, 30–38, 40, 42–45.

Horizontal Sections—

Sheets 18, 43, 44, 60–70, 85–102, 137, 146, 157.

GENERAL MEMOIRS

1869. The Triassic and Permian Rocks of the Midland Counties of England.
1877. The Superficial Geology of the Country adjoining the Coasts of South-west Lancashire.
1878. The Geology of the Yorkshire Coalfield.
1910. Guide to the Geological Model of Ingleborough and District.
1914. The Water Supply of Nottinghamshire from Underground Sources.
1923–58. The Fossil Plants of the Carboniferous Rocks of Great Britain; first section in six parts. 1923–5, second section 1955–
1929. Wells and Springs of Derbyshire.
1952. The Concealed Coalfield of Yorkshire and Nottinghamshire. Edit. 3.

Between the years 1915 and 1929, thirty-one special reports on the Mineral Resources (Coal excepted) of Great Britain were issued by the Geological Survey. In many of these there are descriptions of mines and mineral occurrences in the Pennines and adjacent areas.

Sheet Memoirs

Memoirs descriptive of the majority of the one-inch geological maps have been published. Many of those referring to Old Series maps are now out of print and are not listed below. A descriptive memoir accompanies many New Series one-inch maps. Those in course of preparation are marked with an asterisk.

Old Series

Wakefield and Pontefract (87 N.W.); Bradford and Skipton (92 S.E.); Parts of Nottinghamshire and Derbyshire (82 S.E.); Nottingham (71 N.E.); Prescot (80 N.W.); Chester (89 S.W.); North-East of York (93 N.E.); Northallerton and Thirsk (96 N.W. and 96 S.W.); Kendal, Sedbergh, Bowness and Tebay (98 N.E.); Ingleborough (97 S.W.); Mallerstang, with parts of Wensleydale, Swaledale, and Arkendale (97 N.W.).

New Series

North and East of Harrogate (62); Clitheroe (68); Bradford (69); Leeds (70); Southport and Formby (74 and 83); Preston (75)*; Rossendale Anticline (76); Huddersfield and Halifax (77); Wakefield (78); Wigan (84); Manchester (85); Holmfirth and Glossop (86); Barnsley (87); Liverpool (96); Runcorn (97)*; Chapel en le Frith (99)*; Sheffield (100); Macclesfield, Congleton and Crewe (110); Northern Part of Derbyshire Coalfield (112 and part of 100); Chesterfield (112)*; Ollerton (113); Country between Newark and Nottingham (126); Nottingham (Special Sheet).

Short List of Other Works

(Full bibliographies are published in Geological Survey memoirs.)

Armstrong, A. L. 1931. Excavations in the Pin Hole Cave, Creswell Crags, Derbyshire. *Proc. Prehist. Soc. E. Anglia*, vol. vi, pp. 330–34.

Bemrose, H. H. Arnold. 1907. The Toadstones of Derbyshire: their Field-Relations and Petrography. *Quart. Journ. Geol. Soc.*, vol. lxiii, pp. 241–81.

Bisat, W. S. 1924. The Carboniferous goniatites of the North of England and their zones, *Proc. Yorks. Geol. Soc.*, vol. xx, pp. 40–124.

Bond, G. 1950. The nomenclature of Lower Carboniferous 'Reef' Limestones in the North of England. *Geol. Mag.*, vol. lxxxvii, pp. 267–78.

Chubb, L. J., and R. G. S. Hudson. 1925. The nature of the junction between the Lower Carboniferous and the Millstone Grit of North-West Yorkshire. *Proc. Yorks. Geol. Soc.*, vol. xx, pp. 257–91.

Clift, S. G. and A. E. Trueman. 1929. The sequence of non-marine lamellibranchs in the Coal Measures of Nottinghamshire and Derbyshire. *Quart. Journ. Geol. Soc.*, vol. lxxxv, pp. 77–108.

Cope, F. W. 1933. The Lower Carboniferous succession in the Wye Valley region of North Derbyshire. *Journ. Manch. Geol. Assoc.*, vol. i, pp. 125–45.

———. 1949. Woodale borehole, near Buxton, Derbyshire. *In* Abstr. Proc. Geol. Soc., *Quart. Journ. Geol. Soc.*, vol. cv, p. iv.

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